AL.2.1990-158

REPORT #
RRTAC 89-6

CANADIANA

JUN - 7 1990

Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta

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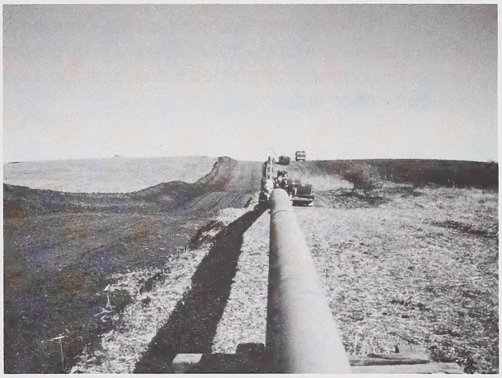

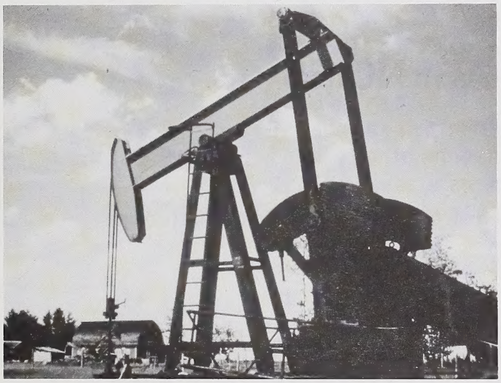

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CO-FUNDING AGENCIES

RRTAC would like to thank the Alberta Research Council for co-funding this project.

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EXECUTIVE SUMMARY

In October 1986 a research project was initiated to provide a scientific basis for development of guidelines for drilling - mud - solids - disposal that optimizes environmental safety and cost effectiveness. In the first phase of the project, detailed sampling, characterization work and a greenhouse study relative to freshwater gel, KCl, and NaCl wastes from the Cold Lake region were completed. In the second phase, detailed sampling, characterization work and a greenhouse study relative to freshwater gel, KCl, and invert wastes from the Foothills region and DAP waste from the Cold Lake region were completed. In the third phase of the study, detailed sampling, characterization work and a greenhouse study relative to freshwater gel and invert wastes from the Grande Prairie area and NaCl waste from the Slave Lake (Red Earth Creek) area were completed.

This research project had two specific goals:

1. to characterize the drilling wastes resulting from different mud systems currently used in Alberta;
2. to assess the effect on soils and changes in growth and trace element content of vegetation as a function of different concentrations of wastes mixed with soil.

Three depths at each of five holes or locations in each of the waste types and liquid and solid phases were sampled wherever possible. The bulk soils used in the greenhouse pot trials were obtained in the vicinity of the waste sampling locations.

The 164 liquid phase samples representing five waste types were analysed for EC, pH, and several anions and cations. The pH values for most of the wastes were in the upper range of values that are encountered in most natural and soil waters. Samples from the KCl and NaCl sumps had EC levels exceeding the values known to impede plant growth. The trace element contents of the liquid samples were generally low with many of the elements below the detection limit of the ICP-AES instrument. The liquid phases of all wastes were generally unsuitable for the uses of drinking, aquatic life,

irrigation and livestock because of the levels of various constituents.

The mean pH values of the solid phase materials ranged from about 8.0 to 10.0. The ANC (Acid Neutralizing Capacity) and lime values indicated that all the wastes had some potential as lime amendments. The mean oil contents ranged from 0.04 to 7.69% with the higher values occurring in the KCl and invert wastes. With the exception of a few values for the freshwater gel samples, the mean EC values which ranged from 4.89 dS/m to 156 dS/m rendered all wastes unsuitable as a plant growth medium. The total elemental analysis data indicated that the mean values for the various elements were within the range of values normally found in soils except for Na, K, Mg, Mo, and Zn.

Calcite, quartz and kaolinite were found in all of the wastes sampled. Barite, dolomite, portlandite, illite, sylvite, and montmorillonite were also detected in some of the wastes.

The GC-MS spectra of the oil fractions extracted from the wastes indicated that organic compounds were not evident in the acid or base fractions but concentrated in the neutral fraction. Further fractionation and analysis was completed with the largest fraction being identified as saturated hydrocarbons with lesser amounts of PAH's.

Comparison of the means for the liquid phase data indicated that depth was more significant than horizontal position. The reverse was true for the data pertinent to the solid phase materials. The number of samples required to characterize the liquid phase wastes was quite variable, particularly for some of the trace elements. The number of samples required to determine pH ranged from one to ten. The number of samples required to characterize the solid phase wastes also varied widely with the lowest number of samples required to determine pH. Most of the trace element levels could have been characterized with less than 20 samples and in many cases with less than 10 samples at 20% accuracy. Overall, the invert wastes required the lowest number of samples to complete the characterization relative to the parameters involved.

Three separate greenhouse experiments were conducted to coincide with the respective sampling and characterization activities. The rates of waste material added were based on chloride content (kg Cl/ha) and liming potential. The chloride rates generally included 0, 200, 400, 600, 800, 1200, and 2400 kg Cl/ha.

Plant growth was enhanced to some extent by the addition of all wastes except the invert to the respective soil materials. For most of the wastes the greatest mean height was achieved at the lowest waste application rate and height decreased as waste concentration increased. There were significant differences in yield relative to waste application rate for most treatments. Significant reductions in yield from the control values occurred as invert waste application rate increased. For the remaining treatments, the lower waste application rates enhanced yield which then decreased as waste concentration increased.

Significant increases in pH, $CaCO_3$ equivalent, EC, SAR and Cl content resulted from the addition of all waste types to the respective soils. The EC levels achieved could be limiting to plant growth at some of the higher rates utilized for all wastes and the SAR values suggested that potential limitations could occur with increasing concentration of freshwater gel, DAP and NaCl waste application.

Significant differences in the elemental content of the brome grass grown in all types of waste/soil mixtures occurred. The highest tissue chloride levels were associated with the invert, KCl and NaCl waste/soil mixtures. Tissue calcium levels generally increased with increasing application rate of invert, KCl and NaCl wastes and decreased with increasing application rates of freshwater gel and DAP wastes. Addition of waste to the Cold Lake and Waterton soils increased plant tissue copper levels from the deficient to the normal range.

Overall, the results obtained indicated both positive and negative impacts on the plants and soils resulting from the different wastes and the respective application rates. The lime content of the wastes is considered a positive characteristic. The EC, SAR and to a lesser extent pH, were the only measured factors that appeared potentially limiting to plant growth depending upon specific waste type and application rate. The organic compounds identified were made up largely of saturated hydrocarbons with lesser amounts of PAH's. The PAH's would pose the greatest challenge environmentally as they weather and degrade slowly.

A description of the general procedures that should be employed to obtain appropriate samples for analyses is provided. Details regarding when and how to sample are provided.

The use of chloride addition as the criteria for determining KCl, NaCl and invert waste application rates appears to be appropriate. Liming potential in conjunction with chloride content would likely be a more appropriate criterion for determination of application rates for the DAP and freshwater gel wastes.

It is recommended that a field trial(s) be undertaken to verify the initial results obtained from the greenhouse component of this study regarding the impact of waste addition to soils. Emphasis should be placed on working with invert wastes as some work is currently underway regarding freshwater gel, KCl, and NaCl wastes. Research is also needed to evaluate the relative contribution to the overall impact of the salts and oils contained in invert wastes.

ABSTRACT

In 1986 the Terrain Sciences Department initiated a research project to provide a scientific basis for development of guidelines for drilling mud disposal. The three phases of the project involved detailed sampling, characterization and greenhouse studies relative to drilling wastes from the Cold Lake, Foothills and Grande Prairie/Peace River regions. Three depths at each of five locations for both the liquid and solid phases of DAP, freshwater gel, invert, KCl and NaCl wastes were sampled. The liquid phases of all wastes were generally unsuitable for the uses of drinking, aquatic life, irrigation and livestock. The mean pH values of the solid phase materials ranged from about 8.0 to 10.0. The ANC (Acid Neutralizing Capacity) and lime values indicated that all of the wastes had some potential as lime amendments. The mean oil contents ranged from 0.04 to 7.69%. With the exception of a few values for the freshwater gel samples, the mean EC values which ranged from 4.89 dS/m to 156 dS/m rendered all wastes unsuitable as a plant growth medium. The total elemental analysis data indicated that the mean values for most of the elements were within the range of values normally found in soils. The GC-MS spectra of the oil fractions extracted from the wastes indicated that organic compounds were concentrated in the neutral fraction. The rates of waste material added to soil in the greenhouse experiments were based on chloride content and liming potential. Plant growth was enhanced to some extent by the addition of all wastes except the invert. Significant increases in pH, $CaCO_3$ equivalent, EC, SAR and Cl content resulted from the addition of all waste types. Significant differences in the elemental content of the brome grass grown in all types of waste/soil mixtures occurred. The results of the greenhouse work suggested that the use of chloride addition as the criteria for determining KCl, NaCl and invert waste application rates appears to be appropriate. Liming potential in conjunction with chloride content would likely be a more appropriate criterion for determination of application rates for the DAP and freshwater gel wastes.

ACKNOWLEDGEMENTS

We would like to recognize the support of the Reclamation Research Technical Advisory Committee (RRTAC) in providing funds from the Alberta Heritage Savings Trust Fund, Land Reclamation Program. The advice and assistance of the Oil and Gas Reclamation Research Program Subcommittee is gratefully acknowledged. The assistance of David Lloyd of Alberta Forestry, Lands and Wildlife, Public Lands Division, in getting the program initiated and the logistical support relative to the field sampling provided by David and his colleagues Brian Kremeniuk, Jeff Hartley, Gail Tucker and others is also gratefully acknowledged. We acknowledge the assistance of Alberta Research Council staff including Dean Stein who assisted with sampling in the Grande Prairie region and Messrs. Joe Beres, Wayne McKean, Darrell Reid and Alex Schwarzer who completed most of the analytical work. Our study would not have been possible without the co-operation of Esso Resources Canada Ltd., British Petroleum Resources Canada Ltd., Bow Valley Industries Ltd., Gulf Canada Resources Ltd., Petro-Canada Inc., and Shell Canada Limited who allowed access to their sump sites.

1. INTRODUCTION

Three basic drilling muds and variations thereof are used for oil and gas exploration in Alberta. These include the freshwater gel bentonite, the salt water systems which use sodium or potassium, and the oil invert mud.

The wastes produced from drilling operations contain many complex organic and inorganic compounds that are added at various stages of the drilling process. The materials that start out as a drilling mud before going down hole are usually quite altered once they enter a waste pit. Chemically and physically the muds can be altered by heat and pressure effects associated with drilling and by the addition of drill cuttings brought up with the mud system. The materials found in the waste pit can also be changed chemically and physically by other products that are purposely or inadvertently added to the pit.

Drilling wastes are currently disposed of by burying, trenching, squeezing, and spreading. Each of these disposal methods impacts the environment in different ways. For example, interactions of waste constituents with groundwater is much more likely to occur if wastes are trenched or buried as opposed to surface spread. The reverse is true for soils and plants. Review of the literature indicates that effects of disposal of drilling wastes on plants and soils varies with the type of waste, rate of application, and plant species.

A number of researchers have studied the environmental effects of drilling fluids (Ferrante 1981; Forsgren-Perkins Engineering 1982; Honarvar 1975; Miller and Honarvar 1975; Nelson et al. 1984; Peseran 1977; Strosher et al. 1980; and others). In most of these studies only single waste types or components thereof were addressed. For example, Strosher et al. 1980 looked at the environmental effects of the terrestrial disposal of waste drilling muds in Alberta. However, Strosher examined only the fluids and not the solids component and did not examine the sodium chloride or invert muds. Furthermore, Strosher examined simulated drilling mud components for plant toxicity rather than actual sump waste fluids.

Research associated with waste disposal from oil and gas drilling has received a considerable amount of attention in the past five years. The Reclamation Research Technical Advisory Committee (RRTAC) sponsored a seminar on "Gel and Saline Drilling Waste Disposal" in April 1985 to promote a better understanding between government regulators and industry about drilling mud components, waste properties and the environmental considerations regarding disposal of these wastes (Lloyd 1987). Leskiw et al. (1987) completed a literature review and accompanying field manual in an attempt to identify practical methods for environmentally acceptable disposition of wastes based on what is "known". They concluded, among a number of other points, that research is needed to determine the form, concentration ranges and total levels of various elements in sump fluids and solids. They also recommended that loadings for various waste constituents on the environment should be established (Leskiw et al. 1987).

Wojtanowicz et al. (1989) completed a field survey of four drilling-mud reserve pits in Louisiana's Wilcox trend to develop pit sampling procedures. The samples were analysed for solids, liquids, rheological properties and contaminants such as, oil, chlorides, and metals (Cr, Pb, Ba, and Zn). From the results of this research a method for the systematic sampling of a drilling-mud reserve pit including the selection of optimum sampling depth and determination of the minimum number of samples to be taken was developed.

Research relative to the impact of land application of drilling wastes has been underway in western Canada for a number of years. Abougendia et al. (1987, 1988) completed an evaluation of land application of oil and gas drilling wastes on soils and crops in the Kindersley and Estevan region and Lloydminster and Swift Current region of Saskatchewan. They found that both growth room and field studies showed that freshwater based drilling wastes applied to agricultural land at a rate of 100 barrels/acre had little or no effect on soil characteristics or plant growth. They recommended that prior to drilling waste application the waste be analysed for total dissolved solids, water soluble ions, pH, and trace element concentration (particularly B, Cr, Cu, Mo, Ni, and Zn).

BP Canada experimented with the landspreading of salt based drilling waste in the Wolf Lake area of Alberta (Alberta Report 1988). Drilling mud wastes were disk-ploughed into 60 acres at old industrial sites which were then seeded with a recommended grass-legume mix. No adverse effects on the forage crop or the water table became apparent.

Ashworth et al. (1989) undertook to assess the feasibility of land application as a waste management practice for disposal of residual diesel invert muds and cuttings in the foothills of Alberta. Soil amendments included manure, charcoal and spent carbon granules following the incorporation of the waste material into the soil. Because the study was not yet completed the authors indicated that it was not yet possible to draw general reliable conclusions.

It became apparent that knowledge of the concentration ranges of the different constituents found in sumps and the effect of these constituents on the environment is somewhat lacking in Alberta. A thorough physical and chemical analysis of the liquid and solid phases of wastes generated by drilling operations utilizing the different mud types is one of the prerequisites to assessing environmental hazard of the disposal of these wastes and to allow for development of sound recommendations. This is particularly important in light of the fact that a joint industry and government "Drilling Waste Review Committee" is presently reviewing current criteria and drilling waste disposal practices in Alberta and is preparing an updated document.

This report represents a summary or overview of reports prepared by the Alberta Research Council for RRTAC pertinent to the Cold Lake region (Macyk et al. 1987a, 1987b), the Foothills region (Macyk et al. 1988), and the Grande Prairie/Peace river region (Macyk et al. 1989).

2. OBJECTIVE

This research project was initiated to provide a scientific basis for development of guidelines for drilling-mud-solids-disposal that optimizes environmental safety and cost effectiveness by conducting research to identify environmental limitations of available disposal technology. The subobjectives were to:

1. characterize the drilling wastes resulting from different mud systems currently used in the Cold Lake, Foothills, and Grande Prairie/Peace River regions; and,
2. assess the effect on soil properties, and the changes in growth and trace element content of vegetation, as a function of different concentrations of wastes mixed with soil.

3. MATERIALS AND METHODS

3.1 SAMPLING

3.1.1 Sample Site Location

The sampling program involved collection of wastes from sumps in the Cold Lake, Eastern Slopes (Foothills), and the Grande Prairie/Peace River regions of the province. The freshwater gel, KCl, and NaCl wastes were sampled during the period October 27 to 29 and November 13, 1986, and the DAP sump on July 15, 1987 in the Cold Lake area (Figure 1). Details pertinent to the sample point locations within the individual sumps are provided in Figures 2, 3, and 4.

Sampling of the freshwater gel and KCl wastes in the Pincher Creek area was completed June 12, 1987 (Figures 4 and 5). Sampling of the water (no additives), freshwater gel, and invert sumps in the Rocky Mountain area was completed June 10, 1987 (Figures 6 and 7).

Sampling of the freshwater gel and invert wastes in the Grande Prairie area was completed during the period June 21 to 23, 1988 (Figures 8 to 10). The NaCl waste in the Red Earth Creek area was sampled July 27, 1988 (Figures 11 and 12).

3.1.2 Waste Sampling Methodology

Samples of the solid and liquid phases were obtained for most of the waste types and sites sampled. Wherever possible a total of five points or horizontal positions with three depths at each position were sampled in both of the liquid and solid phases. This resulted in the acquisition of a total of 15 samples in each of the liquid and solid phases for each waste sampled. Exceptions to this practice included sites where shallow materials precluded the sampling of three depths and sites such as the freshwater gel waste site in the Rocky Mountain House area which did not have a liquid phase cell.

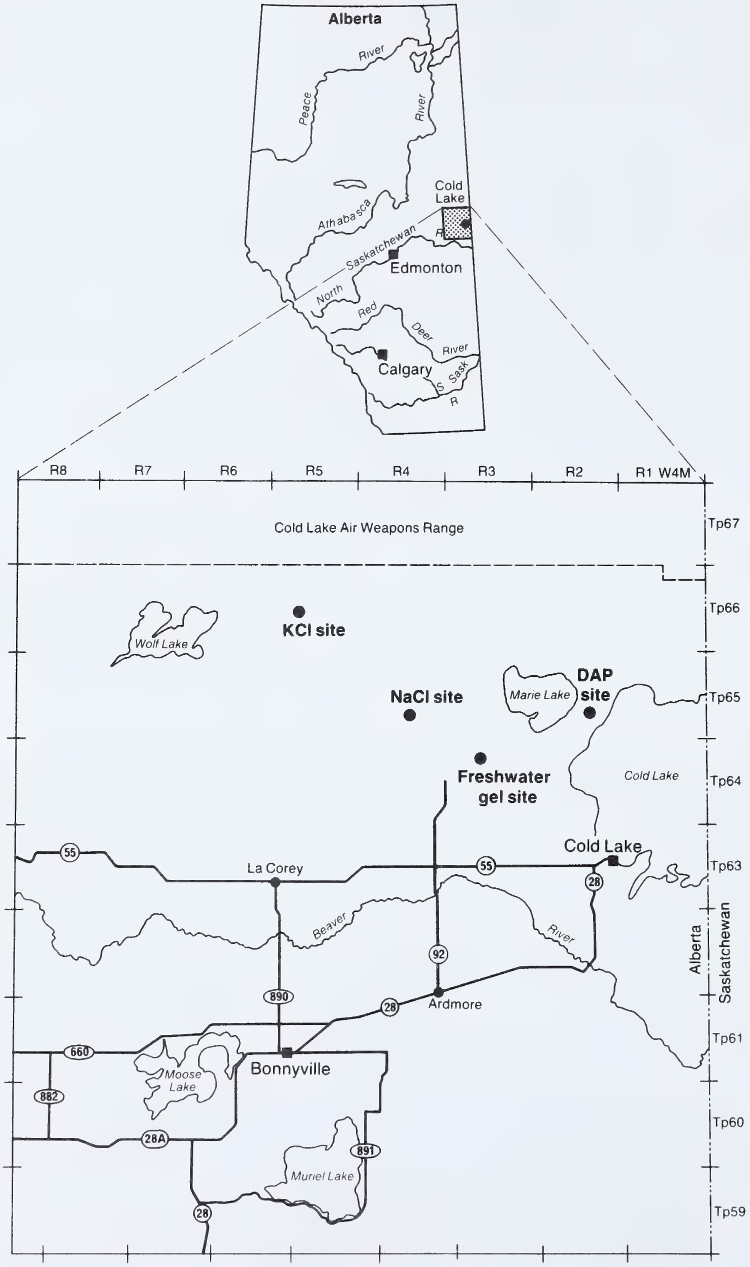


Figure 1. Drilling waste sample site locations in the Cold Lake region.

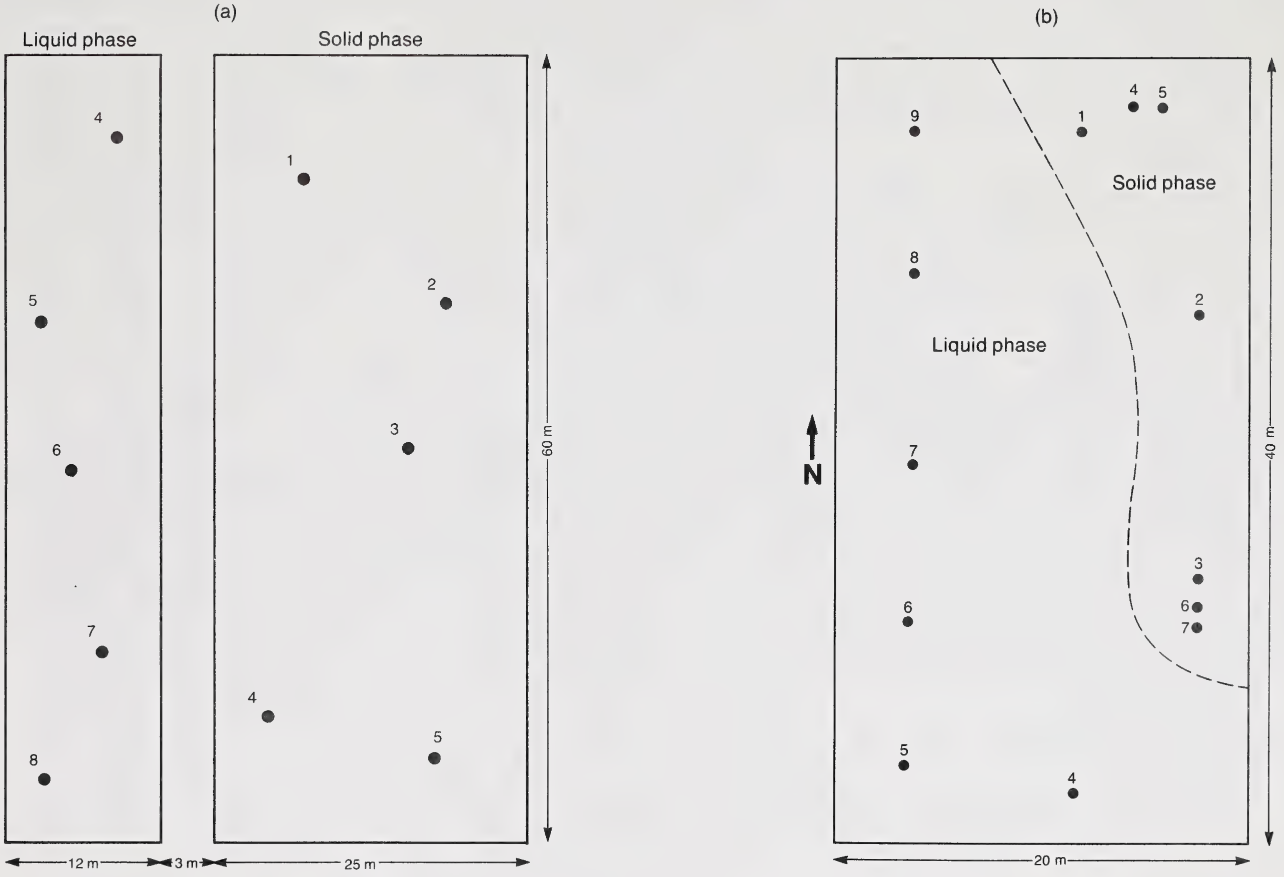
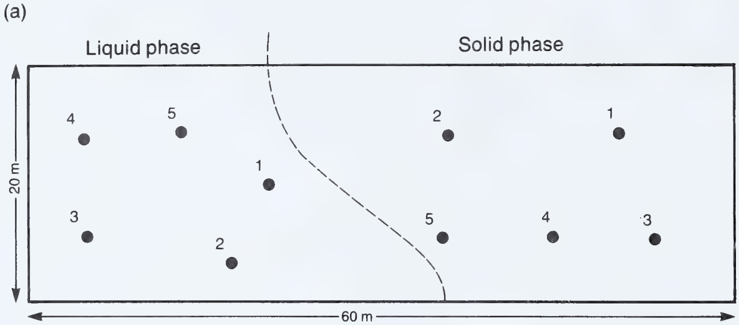
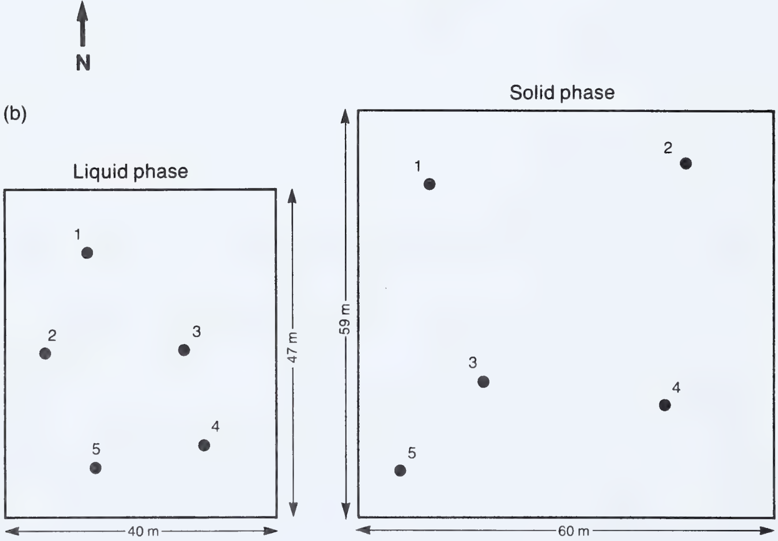


Figure 2. Freshwater gel (a) and Diammonium phosphate (DAP) (b) sump sample point distribution in the Cold Lake region.



Sodium chloride



Potassium chloride

Figure 3. Sodium chloride (a) and potassium chloride (b) sump sample point distribution in the Cold Lake region.

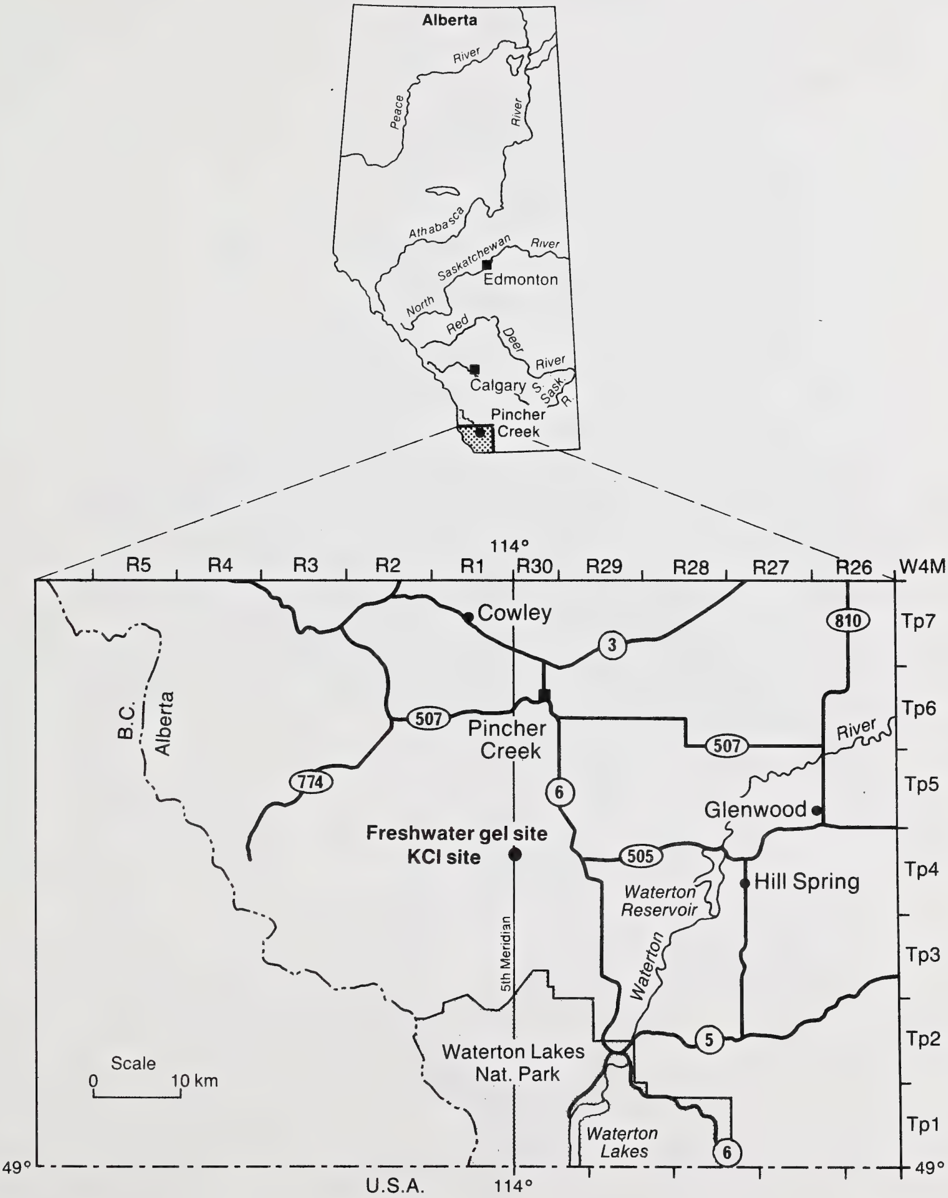


Figure 4. Drilling waste sample site locations in the Foothills (Pincher Creek) region.

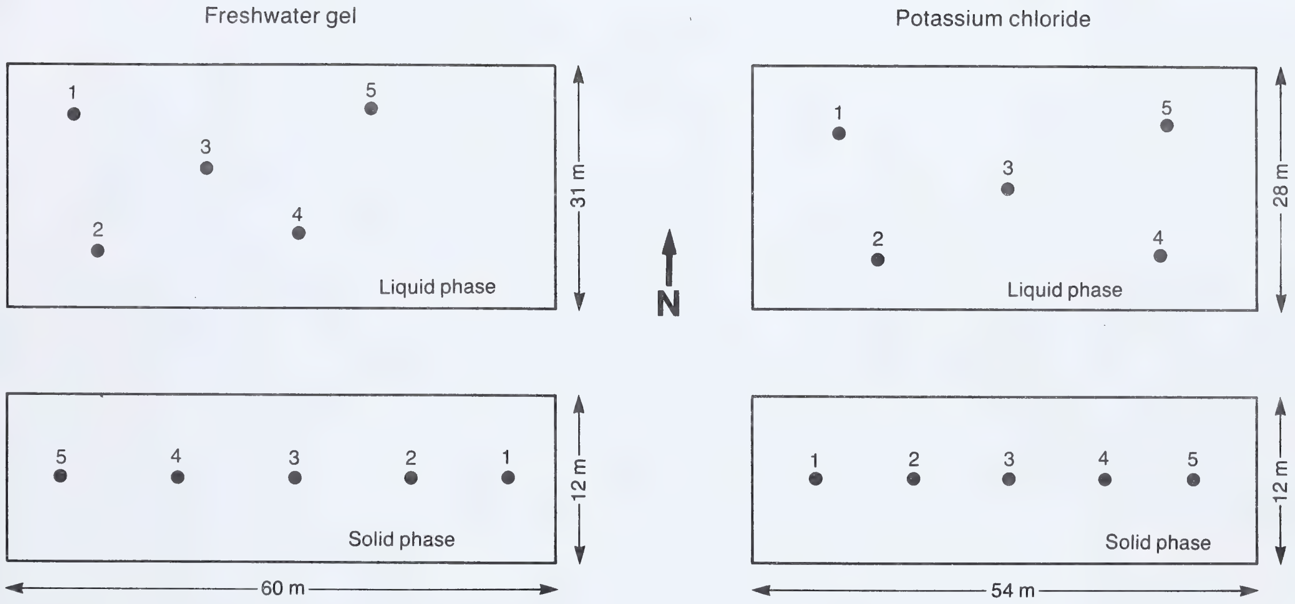


Figure 5. Freshwater gel and potassium chloride sample point distribution in Pincher Creek area.

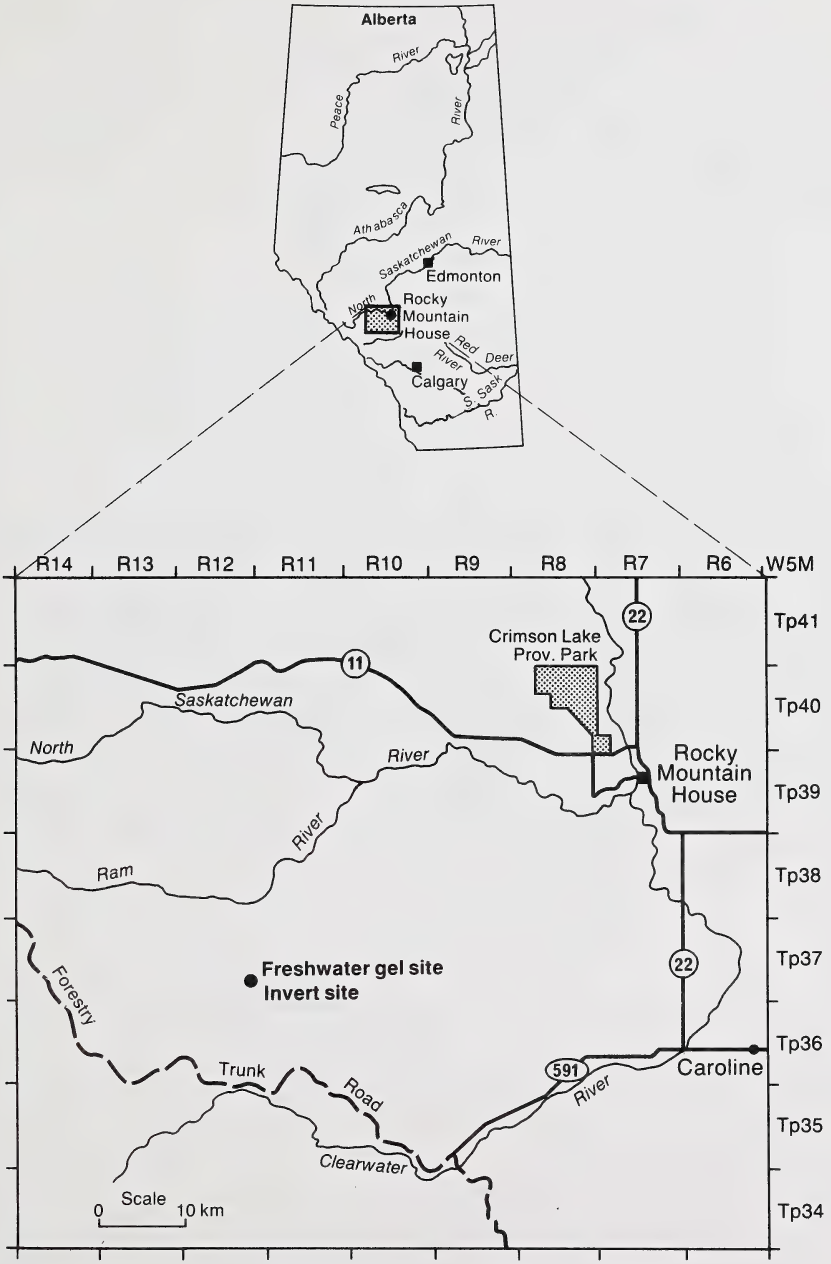


Figure 6. Drilling waste sample site locations in the Foothills (Rocky Mountain House) region.

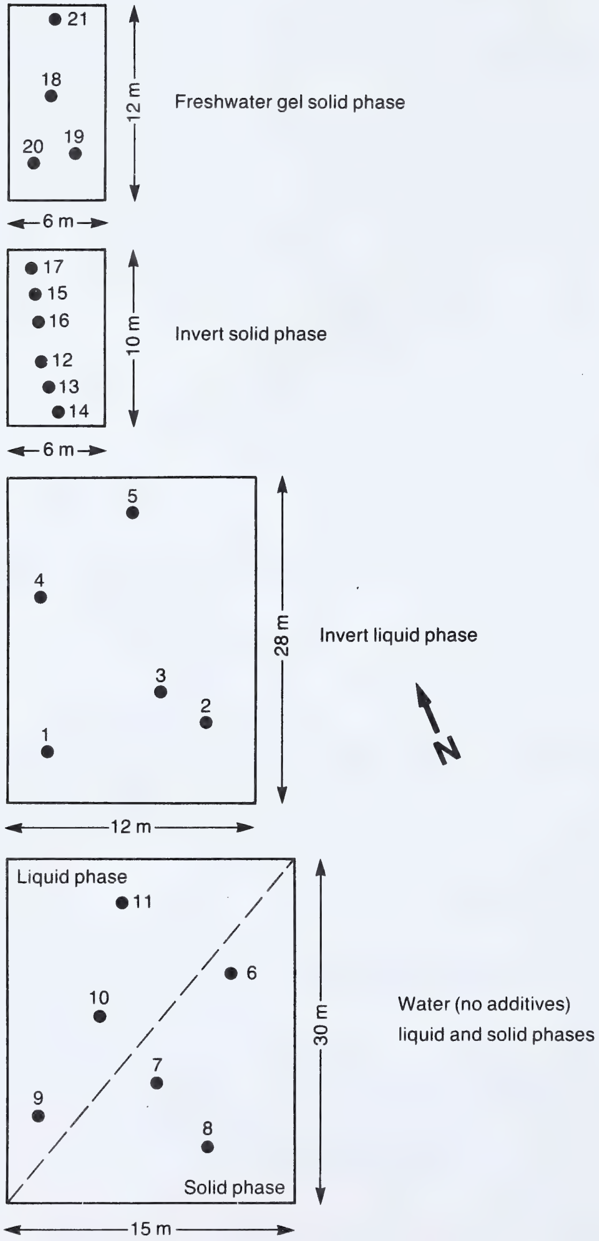


Figure 7. Sump sample point distribution in the Rocky Mountain House area.

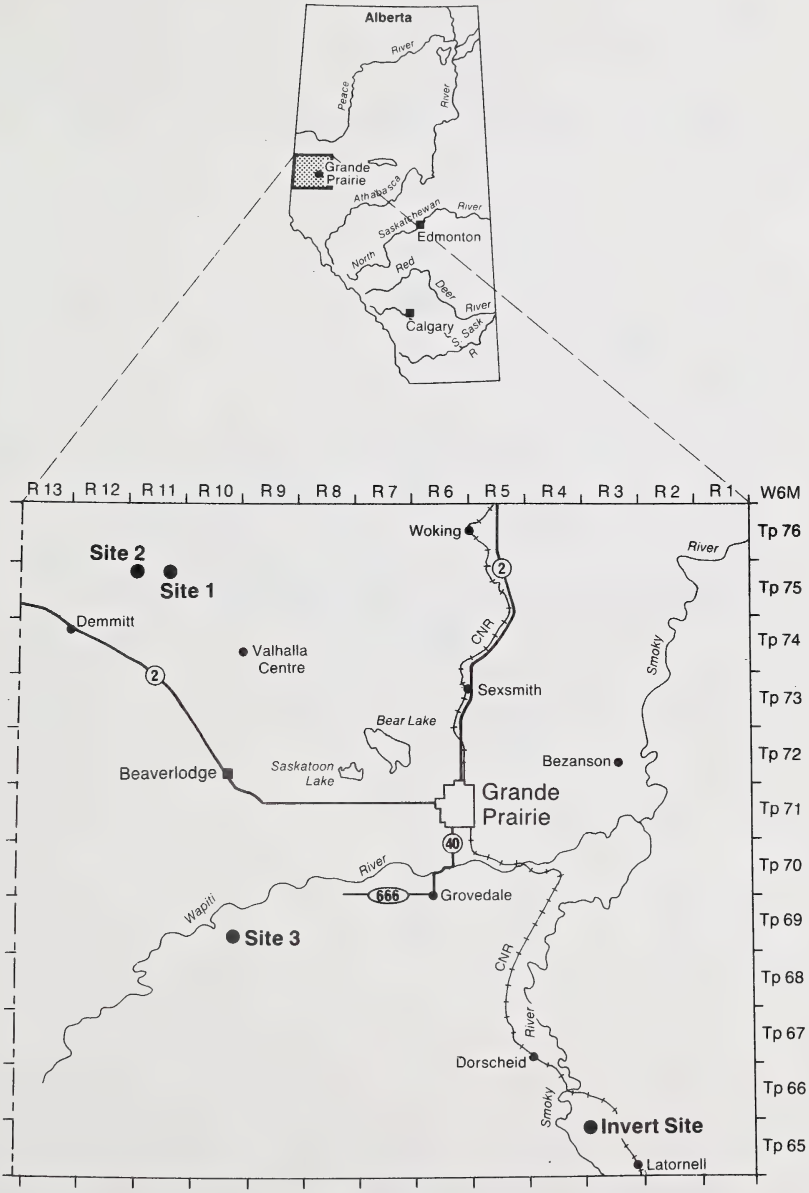


Figure 8. Sampling locations for freshwater gel waste (sites 1, 2, 3) and invert waste in the Grande Prairie area.

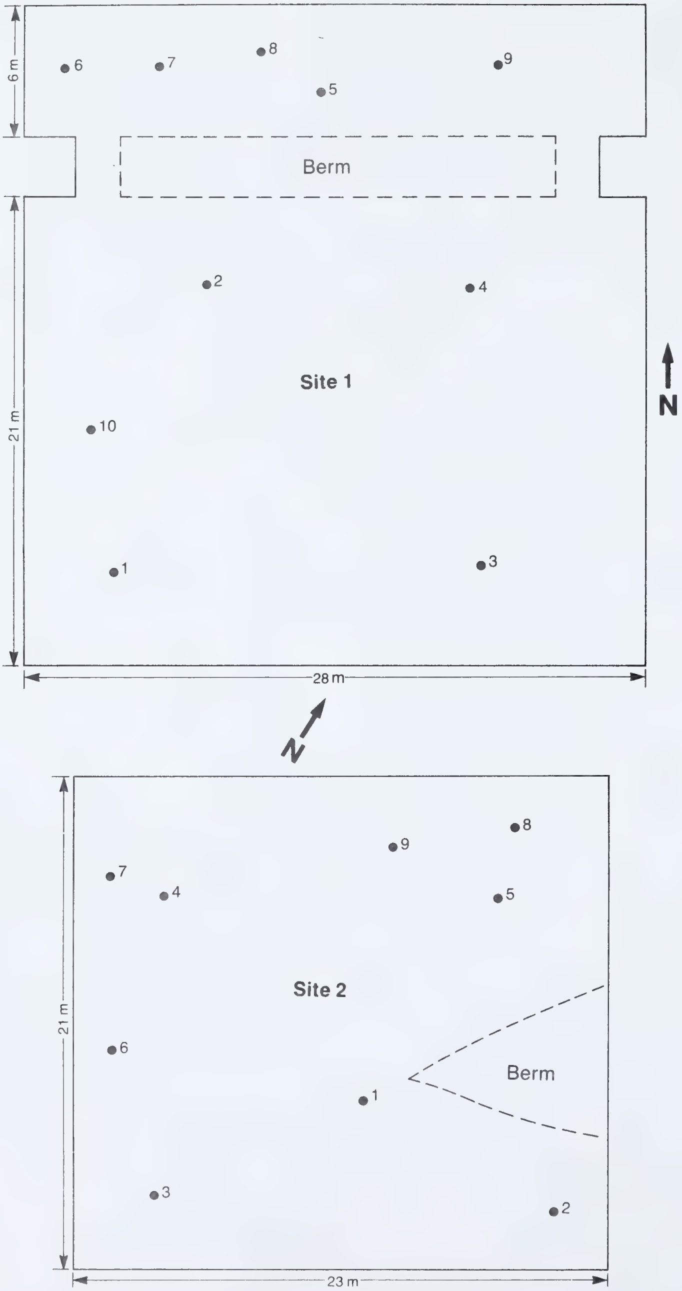


Figure 9. Freshwater gel sump sample point distribution in the Grande Prairie area.

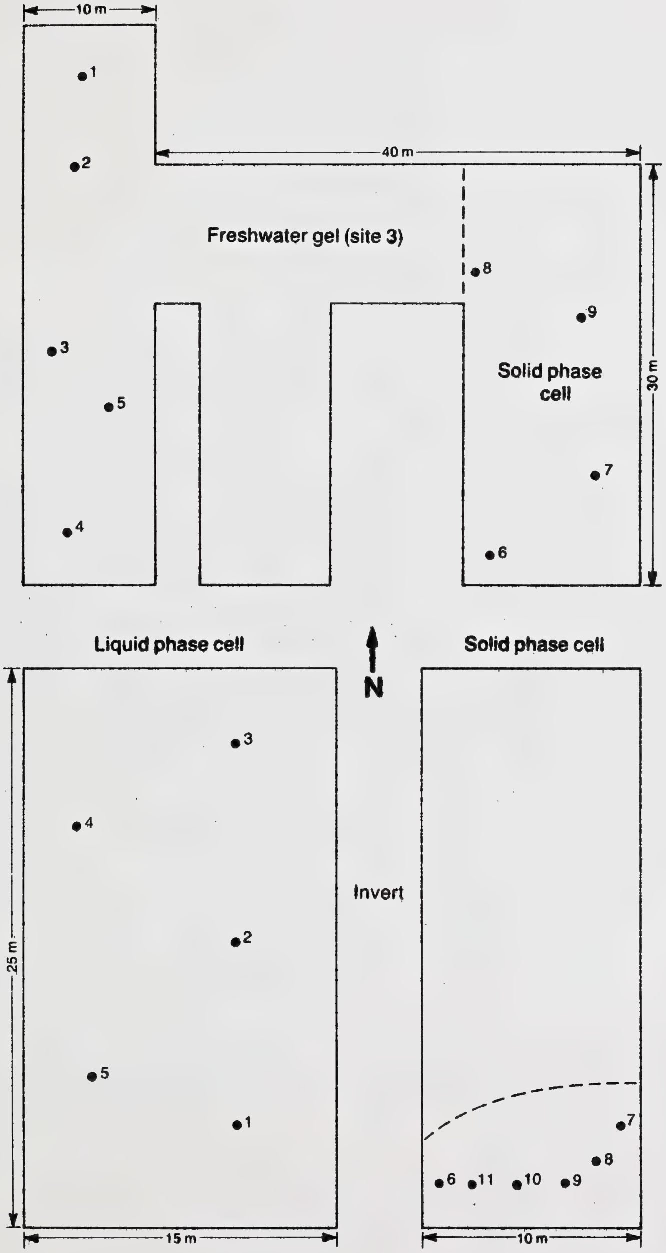


Figure 10. Freshwater gel (site 3) and invert sump sample point distribution in the Grande Prairie area.

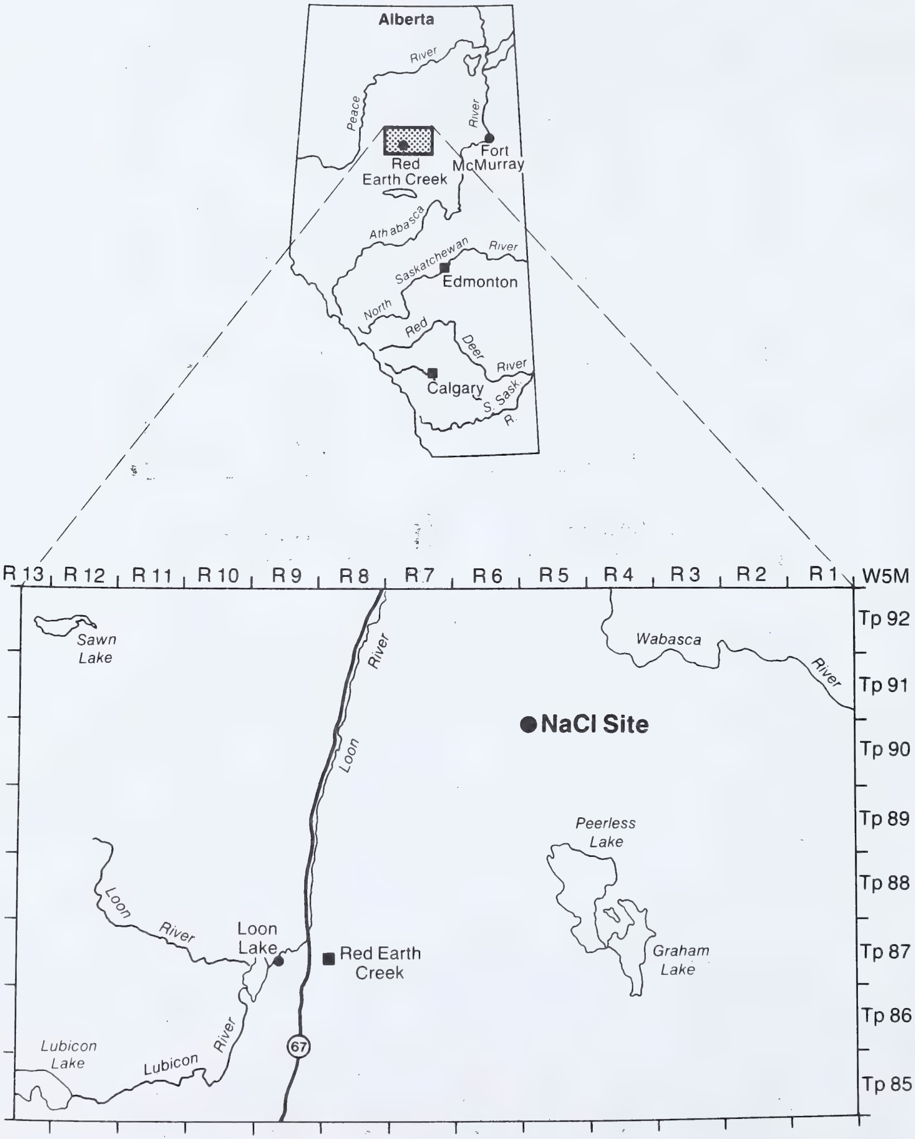


Figure 11. Sodium chloride waste sample site location in the Red Earth Creek area.

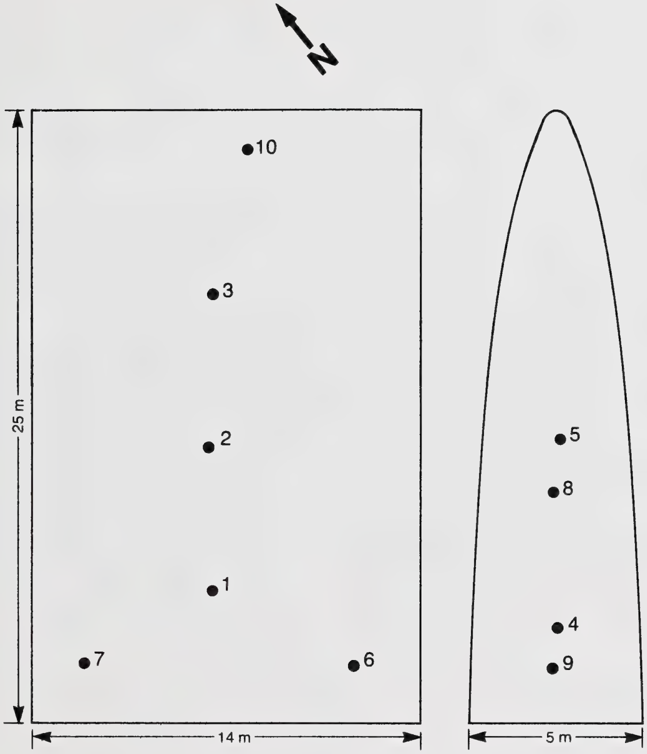


Figure 12. Sodium chloride sump sample point distribution in the Red Earth Creek area.

Details pertinent to the depths sampled and the number of samples obtained are included in Tables 1 to 3 for the respective regions of the province. Sample depth intervals were kept uniform within the individual sumps to the extent possible.

The solid phase samples were collected and transported in both plastic bags and glass jars, whereas the liquid phase samples were collected in both plastic bottles and glass jars. Glass containers are required for samples that will be analysed for organics. The bulk samples for the pot trials were a composite of material from all digs and depth intervals within each sump. These materials were collected and transported in clear plastic lined pails.

A variety of hand tools and backhoes were used for sampling the solid materials. A few of the sumps were partially trafficable allowing for sampling to be done with hand tools.

A "discrete entity" sampler was designed and used to replace the pump system originally used for sampling the liquid materials. Boats or dinghies were used for transportation on the liquid sump cells.

3.1.3 Pot Trial Soil Sampling

The bulk soil materials from the Cold Lake area for use in the greenhouse pot trials were obtained from Orthic Gray Luvisols in the vicinity of the sumps. The upper 30 cm of the respective profiles including the LFH, Ae, AB, and upper portion of the Bt horizons were collected.

The bulk soil sample from the Rocky Mountain House area was obtained from an Orthic Gray Luvisol/Eluviated Eutric Brunisol soil site near the sump. The upper 25 cm of the profile including the LFH, Ae, and upper portion of the B horizons were collected.

The bulk soil sample from the Pincher Creek area was obtained from an Orthic Black Chernozem soil site adjacent to the sumps. The upper 25 cm of the soil profile comprised mainly of Ah or

Table 1. Sampling details for the Cold Lake region.

		Liquid Phase		Solid Phase	
Waste Type	Location	Depth (cm[a])	Points[b]	Depth (cm)	Points
Freshwater Gel	LSD6-28-64-3-W4	0 to 15	5	0 to 75	5
		15 to 75	5	75 to 150	5
		75 to 120	4	150 to 225	5
Sodium Chloride	LSD15-10-65-4-W4	0 to 75	5	0 to 75	5
		75 to 150	5	75 to 150	5
		150 to 225	5	150 to 225	5
Potassium Chloride	LSD16-17-66-5-W4	0 to 15	5	0 to 75	5
		15 to 75	5	75 to 150	5
		75 to 150	5	150 to 225	4
Diammonium Phosphate (DAP	LSD8-14-65-2-W4	0 to 15	6	0 to 30	7
				30 to 60	7
				60 to 90	6

[a] Depth (cm) - Depth intervals sampled.

[b] Points - Number of locations (horizontal positions) sampled in each sump.

Table 2. Sampling details for the Foothills region.

		Liquid Phase		Solid Phase	
Waste Type	Location	Depth (cm[a])	Points[b]	Depth (cm)	Points
Freshwater Gel	LSD5-13-37-12-W4	No samples		0 to 50	4
				50 to 125	1
				125 to 200	1
Freshwater Gel	Sec21-4-30-W4	0 to 15	5	0 to 100	5
		15 to 50	5	100 to 225	5
		50 to 100	5	225 to 350	5
Invert	LSD5-13-37-12-W5	0 to 15	5	0 to 50	5
		15 to 30	5	50 to 100	2
				100 to 150	1
Potassium Chloride	Sec21-4-30-W4	0 to 25	5	0 to 75	5
		25 to 75	5	75 to 175	5
		75 to 150	5	175 to 275	5
Water (No Additives)	LSD5-13-37-12-W5	0 to 20	3	0 to 50	3
				50 to 100	3

[a] Depth (cm) - Depth intervals sampled.

[b] Points - Number of locations (horizontal positions) sampled in each sump.

Table 3. Sampling details for the Grande Prairie/Peace River region.

		Liquid Phase		Solid Phase	
Waste Type	Location	Depth (cm[a])	Points[b]	Depth (cm)	Points
Freshwater	Sec26-75-11-W4	0 to 25	5	0 to 75	5
Gel		25 to 50	5	75 to 150	5
(Site 1)		50 to 100	5	150 to 225	5
Freshwater	Sec30-75-11-W6	0 to 25	5	0 to 30	4
Gel		25 to 75	5	30 to 75	4
(Site 2)		75 to 125	5		
Freshwater	Sec11-69-10-W6	0 to 25	5	0 to 50	4
Gel		25 to 75	5		
(Site 3)		75 to 140	5		
Invert	LSD10-31-65-3-W6	0 to 25	5	0 to 50	6
		25 to 75	5	50 to 125	5
		75 to	5		
Sodium	Sec12-31-90-5-W5	0 to 25	5	0 to 15	1
Chloride		25 to 50	2	0 to 20	2
		25 to 75	2	0 to 30	1
		75 to 90	2	0 to 50	1
				15 to 50	1
				20 to 30	2
				50 to 100	2

[a] Depth (cm) - Depth intervals sampled.

[b] Points - Number of locations (horizontal positions) sampled in each sump.

Ap horizon material along with a minor proportion of Bm horizon material were collected.

Bulk soil was collected from the upper 25 to 30 cm of the respective soil profiles in areas adjacent to the sump locations sampled in the Grande Prairie/Peace River area. The soil profiles included a variety of Gray Luvisols developed on medium textured glacial materials.

3.2 ANALYTICAL PROCEDURES

This section describes the materials and methods used for analysis of the liquid and solid wastes, soils used for greenhouse pot experiments, pot soil/waste mixtures following harvest and tissue obtained from the pot experiments. The methods used in setup and management of the greenhouse experiment are also described.

3.2.1 Liquid Phase Waste Analyses

The sump liquid samples were kept at 4°C upon receipt at the laboratory and analysed for soluble ions, pH, and electrical conductivity soon after. The sump solid samples were air dried and ground to pass through a 2 mm stainless steel sieve.

The liquid samples were centrifuged at 25000 g for 15 minutes to separate the colloidal materials and the supernatant liquid analysed for pH using a Radiometer combination electrode and Radiometer PHM82 pH meter, electrical conductivity using a Yellow Springs Instruments conductivity cell and model 32 conductance meter, alkalinity (EPA method 310.2, (EPA 1983)) and chloride (EPA method 325.2, (EPA 1983)) with a Lachat flow injection analysis (FIA) instrument, and the soluble ions (Na, K, Ca, Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn, Mn, Mg, Li, Sr, B, Ba, P, S, Mo, Ni, Se, As, Co, and Si) using an ARL model 34000 simultaneous Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES).

3.2.2 Solid Phase Waste and Soil Analyses

Water content of the sump solid samples was calculated after drying at 105°C for 24 hours. For all of the remaining analyses the samples were air-dried and ground to pass through a 2 mm stainless steel sieve. The pH was measured in a paste (Doughty 1941) and in a 2:1 slurry of 0.01 M $CaCl_2$ (Peech 1965). Total carbon content was measured with a LECO CR12 carbon analyser (Leco Corporation 1979), $CaCO_3$ equivalent by acid dissolution (Bascomb 1961) and acid neutralizing capacity by addition of 0.5 M HCl and back titration with 0.25 M NaOH (methods 1.004 and 1.005 (AOAC 1981)). Saturated pastes were prepared according to the USDA Soil Salinity Laboratory method (Rhoades 1982; USDA 1954); were extracted and the extracts filtered through a 0.45 mm filter and analysed for pH, electrical conductivity, alkalinity, chloride, and for soluble salts (Na, K, Ca, Al, Cr, Fe, V, Ti, Cd, Cu, Pb, Zn, Mn, Mg, Li, Sr, B, Ba, P, S, Mo, Ni, Se, As, Co, Si) using an ARL model 34000 simultaneous Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). Cation exchange capacity (CEC) and extractable cations of the sump solid samples were determined by extraction with a normal (1 M at pH 7.0) ammonium acetate solution (Holmgren et al. 1977), where NH_4 ions were determined by a Tecator Kjeltec Auto 1030 Analyser distillation and titration unit and the exchangeable ions by the ICP-AES. The particle size analysis was done using a simplified hydrometer method (Gee and Bauder 1979).

DTPA-NH_4HCO_3 extractable elements (Fe, Cd, Cu, Pb, Zn, Mn, Ca, Mg, Na, K, B, P, Mo, Ni, Se) were determined by the method of Soltanpour and Workman (1981). Total elemental analysis of the solid sump samples was done by digestion in a CEM microwave digestion system. The procedure used included ashing the material overnight in a 425°C muffle furnace, digestion in a teflon bomb in the microwave oven with 1.5 mL HNO_3, 4.5 mL HCl and 10 mL HF for 10 minutes at 100 percent power, 20 minutes at 50 percent power and 10 minutes at 100 percent power. The digested solutions were transferred and made up with saturated H_3BO_3 to 50 mL, and the metal concentrations measured using ICP-AES. Minerals were identified in the sump solid samples using a Phillips X-ray diffraction (XRD) instrument.

Oil content in the samples was measured gravimetrically by soxhlet extraction with methylene chloride (McGill and Rowell 1977). The methylene chloride extract was separated into acid and base fractions by extracting with HCl and NaOH respectively, and with the remaining neutral fraction were submitted for analysis by gas chromatography mass spectroscopy (GC-MS).

Since the GC-MS scan of the neutral fraction was very complex and not amenable to identification, further separation was necessary to identify the groups of organic compounds present. The neutral fraction was then fractionated further using a modification of the procedure described by Later et al. (1981). The fractionation procedure consisted of separating the neutral extracts into several fractions by chromatography on a neutral alumina column (or on Amicon Sep-Pak cartridges containing neutral alumina) and eluting the organic compounds sequentially with hexane (aliphatic hydrocarbons), benzene (neutral polycyclic aromatic compounds and possibly nitrogen polycyclic aromatic hydrocarbons), methylene chloride and acetonitrile (more polar compounds such as organic acids).

3.2.3 Methods of Plant Analysis

The grass samples were digested with a concentrated HNO_3-$HClO_4$ acid mixture in a teflon bomb heated in a CEM microwave digestion unit and the solution concentration of Al, Fe, Zn, Mn, Ca, Mg, Na, K, Sr, P, Ba, Mo, B, S, Si, and As measured by ICP-AES and Cd and Pb by graphite furnace atomic absorption. Chloride content was determined by the sodium nitrate extraction procedure of Gaines et al. (1984).

3.3 GREENHOUSE POT TRIAL METHODS

3.3.1 Trial Treatments

Soils and wastes from each of the three regions represented in the sampling and characterization program were utilized in the respective greenhouse experiments.

3.3.2 Trial Establishment

The greenhouse experiments were conducted in the University of Alberta Phytotron. The trial periods which extend from the day of seeding to the day of harvest were February 13 to May 19, 1987; November 6, 1987 to January 5, 1988; and October 18, 1988 to January 4, 1989 for the Cold Lake, Foothills, and Grande Prairie/ Peace River greenhouse experiments respectively.

The pots used were 12.7 cm in diameter and accommodated 1 kg of soil and drilling waste mixture. The pots were lined with plastic bags and kept in saucers throughout the trial. The drilling waste and pot trial soils were weighed, mixed, and retained in the same plastic bags throughout the experiment.

Prior to planting, the individual pots were watered to field capacity and fertilized on the basis of results from the available nutrient analysis. The field capacity moisture content values for the wastes and pot soils are presented in Table 4. The amount of water added to the pots varied according to the ratio of waste:soil and the respective field capacity moisture values. Fertilization of the Cold Lake region pots involved the addition of 5 mL of a solution (7.35 g NH_4NO_3 and 5.13 g $NaHPO_4$ in 500 mL solution) to the water added to bring the mixtures to field capacity. Fertilization of the Foothills region and Grande Prairie/Peace River region pots involved the addition of a solution which supplied 50 ppm N, 25 ppm P, and 5 ppm S.

Fifty seeds of certified Carlton brome grass were planted randomly in each pot and covered with 1 cm of soil/waste mixture. Initially 75 seeds were used for the Cold Lake region pot experiment,

Table 4. Field capacity moisture values for the wastes and greenhouse pot soils.

Waste or Pot Soil	Region	Area	Field Capacity Moisture (%)
Freshwater Gel	Cold Lake	-	41
Freshwater Gel	Foothills	Pincher Creek	122
Freshwater Gel	Foothills	Rocky Mtn House	29
Freshwater Gel	Grande Prairie/ Peace River	Grande Prairie	41
KCl	Cold Lake	-	37
KCl	Foothills	Pincher Creek	37
NaCl	Cold Lake	-	41
NaCl	Grande Prairie/ Peace River	Red Earth Creek	63
Invert	Foothills	Rocky Mtn House	15
Invert	Grande Prairie/ Peace River	Grande Prairie	17
Pot Soil	Cold Lake	-	13
Pot Soil	Foothills	Pincher Creek	13
Pot Soil	Foothills	Rocky Mtn House	26
Pot Soil	Grande Prairie/ Peace River	Grande Prairie	26
Pot Soil	Grande Prairie/ Peace River	Red Earth Creek	21

however observations during the span of this study resulted in the reduction in number of seeds for subsequent experiments. The pots were placed in a random order which was changed twice during the experiment.

3.3.3 Trial Maintenance

The greenhouse compartment temperature was maintained between 20 and 25°C during the day and between 15 and 20°C at night. A day length of 16 to 18 hours was achieved by the use of overhead lighting. Moisture content was maintained at or near field capacity by watering on a pot weight basis twice a week.

3.3.4 Growth Measurement

Observations were recorded once a week and photographs were taken once or twice during each of the experiments. At two-week intervals the height of the grass was measured by placing a ruler at the soil surface and reading the average height of the plants.

3.3.5 Harvest Methods

The plants were harvested 1 cm above the surface of the growth medium to minimize potential contamination. The fresh weight of the shoots in each treatment was determined as soon as possible after clipping.

The plants were washed in a dilute metal free detergent solution, rinsed three times in distilled water, dried at 70°C for 24 hours and the dry weights recorded.

Following the harvest, the waste/soil mixture was gently removed from the roots, bagged and labelled for drying. The roots and remaining 1 cm of stalks were washed in a dilute metal free detergent solution, rinsed three times in distilled water and towel dried. Weights of the roots were recorded after towel drying and again after drying for 24 hours at 105°C.

4. RESULTS AND DISCUSSION - CHARACTERIZATION

4.1 LIQUID PHASE WASTES

A total of 164 liquid phase samples were obtained from the various locations. The total included 74 freshwater gel, 26 NaCl, 30 KCl, 25 invert, 6 DAP, and 3 water (no additives) samples. Table 5 provides a comparison of the mean values for the chemical properties of the liquids by location for each of the major waste types. The invert wastes showed significant differences between locations for the smallest number of parameters measured whereas the freshwater gel wastes showed significant differences for the largest number of parameters measured.

The mean pH values ranged from a low of 7.26 for the invert waste from the Grande Prairie area to a high of 9.86 for the NaCl from the Cold Lake location. The pH values for most of the wastes were in the upper range of values that are encountered in most natural and soil waters.

The mean EC values ranged from a low of 0.6 dS/m in the Grande Prairie freshwater gel (Site 2) waste to 32.0 dS/m in the NaCl waste from Cold Lake. The latter value far exceeds the EC levels known to impede plant growth. The values for the invert waste could have a slight to moderate impact on plant growth whereas the freshwater gel waste could have none to a slight limitation to plant growth.

The trace element contents of the liquid samples were generally low with many of the elements below the detection limit of the ICP-AES instrument.

The quality of the sump liquids and their suitability for various purposes were assessed by comparison with the maximum acceptable levels of inorganic constituents in the Canadian water quality guidelines (CCREM 1987) and Table 6. The liquids from all wastes were generally unsuitable for drinking, aquatic life, irrigation and livestock watering because of the levels of various

Table 5. Comparison of the mean values by waste and by location of the chemical properties of the liquid phase samples.

Waste	Location	N	E.C. (dS/m)	pH	Alk	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S
					(mg/L)										
Freshwater	Cold Lake	14	0.67b*	8.36a	311b	304b	6.71b	0.12b	90.2bc	16.8b	4.97b	244ba	2.67b	0.10b	40.4a
Freshwater	Waterton	15	2.69a	8.53a	595a	557a	37.6b	0.34b	421a	54.2a	16.6a	727a	30.6a	1.13a	200a
Freshwater1	G. Prairie	15	1.77ba	8.07a	136c	123d	12.6b	0.42b	120bc	27.3b	3.80b	469ab	4.52b	0.36b	251a
Freshwater2	G. Prairie	15	0.60b	8.89a	292bc	156cd	133a	3.22a	19.6c	11.8b	19.0a	156b	20.9a	0.17b	26.0a
Freshwater3	G. Prairie	15	1.06b	8.04a	226bc	220bc	5.34b	0.10b	193b	29.8b	13.1ba	215b	3.46b	0.22b	26.2a
Invert	Rocky Mtn.	10	3.72a	8.13a	264a	248a	15.3a	0.98a	1930a	671a	19.0a	612a	46.8a	9.99a	37.0b
Invert	G. Prairie	15	2.54a	7.26b	250a	249a	0.54a	0.01a	721b	373a	20.7a	313b	9.67b	0.90b	76.2a
KCl	Cold Lake	15	10.0b	8.21a	108b	107b	1.65a	0.08b	4930b	75.4b	21.1b	2200a	1950b	1.91b	78.2b
KCl	Waterton	15	24.4a	7.88a	291a	285a	6.29a	0.16a	9240a	680a	130a	1930b	6610a	12.0a	456a
NaCl	Cold Lake	15	32.0a	9.86a	415a	171a	169a	75.2a	18500a	64.2a	4.95a	12000a	159a	1.45a	123a
NaCl	Slave Lake	11	1.48b	7.97b	51.0b	48.6b	2.22a	0.17a	413b	41.8a	7.93a	265b	8.22b	0.35b	21.7b

E.C. = Electrical Conductivity; Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Waste	Location	Al	Cr	Fe	V	Ti	Cd	Cu	Pb	Zn	Mn	Li	B	Ba	P
		(mg/L)													
Freshwater	Cold Lake	0.39b	0.02b	0.91b	0.03b	0.09b	0.01a	0.01b	0.10b	0.02b	0.01b	0.10a	0.40a	0.10b	0.10b
Freshwater	Waterton	5.53b	0.39a	2.83b	0.04b	0.04b	0.01a	0.01b	0.10b	0.09ab	0.28a	0.04c	0.22b	0.22b	0.24b
Freshwater1	G. Prairie	0.73b	0.14b	0.40b	0.03b	0.02b	0.01a	0.02b	0.10b	0.06b	0.01b	0.04c	0.08b	0.11b	0.14b
Freshwater2	G. Prairie	131a	0.11b	34.5a	0.26a	1.03a	0.01a	0.04a	0.48a	0.16a	0.11b	0.06b	0.39a	0.93a	11.6a
Freshwater3	G. Prairie	1.11b	0.04b	0.44b	0.03b	0.03b	0.01a	0.02b	0.10b	0.03b	0.04b	0.04c	0.07b	0.09b	0.15b
Invert	Rocky Mtn.	2.53a	0.02a	0.01b	0.03a	0.02a	0.01a	0.08a	0.10a	0.10a	0.06b	0.33a	0.68a	0.33a	0.12b
Invert	G. Prairie	1.31a	0.02a	0.06a	0.03a	0.02a	0.01a	0.01b	0.10a	0.04b	0.13a	0.07b	0.15b	0.22a	0.31b
KCl	Cold Lake	0.200b	0.02a	0.01b	0.03a	0.01a	0.01a	0.01a	0.10a	0.02b	0.01b	0.30b	4.58a	0.40a	0.10b
KCl	Waterton	2.87a	0.02a	1.24a	0.03a	0.01a	0.01a	0.01a	0.10a	0.18a	1.78a	0.33a	0.39b	0.08b	0.32a
NaCl	Cold Lake	0.200b	0.02a	0.01a	0.03a	0.01a	0.01a	0.01b	0.10a	0.02b	0.10a	0.10a	0.15a	0.13a	0.10a
NaCl	Slave Lake	0.404a	0.02a	0.236a	0.03a	0.01a	0.01a	0.02a	0.10a	0.04a	0.09a	0.04a	0.05b	0.10a	0.10a

Table 6. Maximum acceptable concentrations of various constituents in Canadian waters.

Constituent	Drinking Water	Aquatic Life Freshwater	Irrigation Water	Livestock Drinking Water
Al	-	0.005-0.1	5-20	5.0
As	0.05	0.05	0.1-2.0	0.5-5.0
Ba	1.0	-	-	-
B	5.0	-	0.5-6.0	5.0
Cd	0.005	0.0002-0.0018	0.01	0.02
Ca	-	-	-	1000
Cl	250	-	100-700	-
Cr	0.05	0.02-2.0	0.1	1.0
Co	-	-	0.05-5.0	1.0
Cu	1.0	0.002-0.004	0.2-5.0	0.5-5.0
Fe	0.3	0.3	5.0-20	-
Pb	0.05	0.001-0.007	0.2-2.0	0.1
Li	-	-	2.5	-
Mn	0.05	-	0.2-10	-
Hg	0.001	0.0001	-	0.003
Mo	-	-	0.01-0.05	0.5
Ni	-	0.025-0.150	0.2-2.0	1.0
Se	0.01	0.001	0.02-0.05	0.05
SO_4	500	-	-	1000
V	-	-	0.1-1.0	0.1
Zn	5.0	0.03	1.0-5.0	50
pH	6.5-8.5	6.5-9.0	-	-
TDS	500	-	500-3500	3000

From CCREM (1987).

constituents. Table 7 provides a summary of the constituents that are deemed limiting for the various uses.

4.2 SOLID PHASE WASTES

A total of 163 solid phase samples were obtained from the various locations. These included 63 freshwater gel, 25 NaCl, 29 KCl, 20 invert, 20 DAP and 6 water (no additives) samples.

The solid phase samples were analysed for several chemical and physical properties, soluble ions in saturated paste extracts, plant available trace elements (DTPA extractable), and total elemental content. Oil content complicated the "grinding" procedure and as a result the invert samples had to be prepared by manual procedures. Preparation of samples for particle size analysis was complicated by the presence of large amounts of salts and carbonates.

4.2.1 Chemical and Physical Properties

Table 8 provides a comparison of the mean values for the chemical and physical properties of the solid materials by location for each of the major waste types.

The mean pH values ranged from a low of 7.93 in the Rocky Mountain House invert to a high value of 9.81 for the freshwater gel from the Cold Lake location. Significant differences in mean pH values between sampling locations for a specific waste occurred only for the invert waste.

Acid neutralizing capacity (ANC) mean values ranged from 3.16 to 24.7%. There were no significant differences in mean ANC values between locations for the waste types. Mean values for cation exchange capacity and extractable cations varied to a different extent for each of the waste types with the most significant differences for parameters between locations occurring for the KCl wastes.

Total carbon and oil content were generally highest in the invert and KCl wastes. The mean values for these wastes and the freshwater gel wastes from the Cold Lake and Waterton locations

Table 7. Waste constituent concentrations deemed limiting for various uses.

	Waste Type			
Use	Freshwater Gel	Invert	KCl	NaCl
Drinking Water	As, Cd, Cl, Cr, Fe, Pb, Se	As, Cd, Cl, Mn, Pb, Se	As, Cd, Cl, EC, Mn, Se	As, Cd, Cl, EC, Mn, Pb, Se
Aquatic Life, Freshwater	Al, Cd, Cu, Fe, Pb, Se, Zn	Al, Cd, Cu, Pb, Se, Zn	Al, Cd, Cu, Fe, Pb, Se, Zn	Al, Cd, Cu, Pb, pH, Se, Zn
Irrigation Water	Cr, Mo, Se	Cl, Mo, Se	Cl, Mo, Se	Cl, Mo, Se
Livestock Drinking Water	Al, Se	Se	Se	EC, Se

Table 8. Comparison of the mean values by waste and by location of the chemical and physical properties of the solid phase samples.

Waste	Location	N	pH		ANC	$CaCO_3$ Eq	Extractable Ions					TIC	TOC	TC	Oil
			H_2O	$CaCl_2$			Na	K	Ca	Mg	CEC				
					(%)		(meq/100 g)					(%)			
Freshwater	Cold Lake	15	9.73a*	9.81a	12.1a	5.74ab	16.4a	1.38ab	75.8a	5.76a	24.8ab	0.69ab	2.99a	3.68a	1.33a
Freshwater	Rocky Mtn.	6	9.40a	8.93a	5.29a	5.23ab	6.24a	0.46b	19.5a	1.38a	7.02c	0.63ab	3.05a	3.68a	0.04a
Freshwater	Waterton	15	9.81a	9.45a	7.47a	4.72ab	141a	4.49a	33.2a	2.58a	34.7a	0.57ab	3.37a	3.93a	2.16a
Freshwater1	G. Prairie	15	9.19a	9.20a	10.1a	8.56a	36.1a	0.95b	51.7a	3.07a	20.8b	1.03a	1.44a	2.46a	0.25a
Freshwater2	G. Prairie	8	8.59a	8.55a	3.16a	2.26b	8.88a	0.65b	37.3a	2.38a	15.4bc	0.27b	1.37a	1.64a	0.12a
Freshwater3	G. Prairie	4	8.95a	8.42a	4.93a	4.57ab	20.6a	1.04b	36.8a	2.28a	22.5b	0.55ab	1.14a	1.69a	0.14a
Invert	Rocky Mtn.	9	7.93b	8.07b	5.27a	4.27a	7.72a	1.46a	51.9a	2.25a	10.1b	0.51a	7.53b	8.04b	3.63b
Invert	G. Prairie	11	9.79a	9.55a	4.85a	4.10a	8.64a	1.34a	57.7a	1.23b	12.8a	0.49a	9.54a	10.0a	7.69a
KCl	Cold Lake	14	8.96a	9.27a	8.45a	5.08b	14.6b	28.3b	40.3b	2.23b	20.0a	0.61b	3.65a	4.26a	1.63a
KCl	Waterton	15	8.36a	8.47b	10.7a	8.89a	30.3a	386a	73.9a	15.2a	16.8a	1.07a	6.08a	7.14a	3.83a
NaCl	Cold Lake	15	9.49a	9.82a	18.9a	9.48b	102a	0.70a	74.1b	6.62b	16.5a	1.14b	1.25b	2.39b	0.21b
NaCl	Slave Lake	10	8.85a	8.92a	24.7a	19.2a	42.0b	0.73a	147a	14.5a	14.2a	2.30a	2.23a	4.54a	0.57a

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capacity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Waste	Location	Water	Sand	Silt	Clay
		(%)			
Freshwater	Cold Lake	167b	39ab	37bc	24bc
Freshwater	Rocky Mtn.	30.0b	60a	30cd	10c
Freshwater	Waterton	436a	17bc	17d	66a
Freshwater1	G. Prairie	206b	24bc	38bc	39ab
Freshwater2	G. Prairie	130b	20bc	51a	29bc
Freshwater3	G. Prairie	239ab	11c	44ab	45ab
Invert	Rocky Mtn.	14.7b	40a	41a	19a
Invert	G. Prairie	19.6a	49a	36a	16a
KCl	Cold Lake	80.1b	43a	36a	22b
KCl	Waterton	209a	30b	37a	33a
NaCl	Cold Lake	56.7a	52a	34b	15a
NaCl	Slave Lake	22.9b	42a	40a	18a

exceeded the range of 1 to 2% for oil reported by Overcash and Pal (1979) to be the levels for initiation of adverse plant effects.

The particle size distribution varied widely for the freshwater gel wastes. No significant differences were evident for sand, silt, and clay content of the invert wastes. The freshwater gel wastes generally had the highest clay contents and the lowest sand contents of the major waste types characterized.

4.2.2 Saturated Paste Extract Data

Saturated paste extract data for the wastes indicate the magnitude of the soluble components in a saturated solution of these materials and can be used to assess the suitability of these materials for plant growth and the possibility of trace element transport. Table 9 provides a comparison of the mean values for the saturated paste extract data of the solids by location for each of the major waste types.

The mean EC values varied from 2.74 dS/m at one of the freshwater gel locations to 156 dS/m at the NaCl sump location in the Cold Lake area. With the exception of a few values for the freshwater gel samples the EC values reported in Table 9 render all wastes unsuitable as a plant growth medium.

The mean pH values varied from 7.74 in the invert waste from Rocky Mountain House to 9.75 in the freshwater waste from the Waterton location. The relatively high pH values reported for most of the waste locations could cause problems with the uptake of plant micronutrients such as iron, copper, manganese, and zinc due to reduced solubility at high pH levels.

The soluble ions for the various wastes were dominated in general by the cations Na, K, and Ca, and the anions Cl and SO_4.

Trace element levels in the waste were quite low with a few exceptions and for many of the elements below the detection limits of the ICP instrument. Aluminum, barium, copper, and strontium levels were fairly consistent and higher for samples from both locations of

Table 9. Comparison of the mean values by waste and by location of the saturated paste extract data for the solid phase samples.

Waste	Location	N	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr
											(mg/L)				
Freshwater	Cold Lake	15	106bcd*	7.54ab	9.57a	311ab	128b	139a	44.2a	1040a	178ab	2.48a	1810a	70.3ab	1.38ab
Freshwater	Rocky Mtn.	6	52.3d	2.74b	9.03a	365ab	328ab	36.4a	0.57a	79.8c	6.48b	1.96a	727a	10.6b	0.14b
Freshwater	Waterton	15	249a	8.18ab	9.75a	1380a	695a	686a	3.75a	886ab	9.44b	0.69a	2200a	98.1a	0.331b
Freshwater1	G. Prairie	15	139bc	12.8a	8.84a	270ab	215ab	36.3a	19.3a	305bc	244ab	10.7a	4320a	41.5ab	3.23a
Freshwater2	G. Prairie	8	73.8cd	6.65ab	8.39a	245ab	237ab	7.9a	0.29a	330bc	405a	27.3a	1730a	38.5ab	2.36ab
Freshwater3	G. Prairie	4	166b	5.30ab	8.17a	165b	161b	4.0a	0.13a	1230a	71.7b	2.94a	1360a	19.9b	1.36ab
Invert	Rocky Mtn.	9	41.4a	43.9a	7.74b	258a	257a	1.70b	0.03a	21500a	8240a	150a	3090a	361a	119a
Invert	G. Prairie	11	42.4a	38.9b	8.80a	303a	274a	28.5a	0.62a	1970a	8410a	9.70b	3550a	258b	63.1b
KCl	Cold Lake	14	67.4a	50.2b	8.64a	102b	85.7b	13.7a	2.95a	18300b	1150a	21.1b	4820b	12500b	10.3a
KCl	Waterton	15	65.5a	111a	8.17a	192a	188a	4.39a	0.11a	61000a	2040a	166a	10000a	36900a	48.6a
NaCl	Cold Lake	15	59.2a	156a	9.27a	315a	259a	42.1a	13.7a	98800a	2190a	13.2b	57900a	431a	5.31a
NaCl	Slave Lake	10	65.8a	48.6b	8.22b	636a	613a	23.4a	0.24a	28600b	3370a	290a	12300b	177b	50.2a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Waste	Location	S	Al	Cr	Fe	V	Ti	Cd	Cu	Pb	Zn	Mn	Li	B	Ba
									(mg/L)						
Freshwater	Cold Lake	1060ab*	1.05ab	0.06a	0.03b	0.06a	0.003b	0.01a	0.02a	0.10a	0.19a	0.01a	0.06b	1.29a	0.13a
Freshwater	Rocky Mtn.	389b	5.20a	0.03a	2.11a	0.03a	0.14a	0.01a	0.01a	0.10a	0.15a	0.02a	0.04a	0.15b	0.11a
Freshwater	Waterton	940ab	0.88ab	0.05a	0.47ab	0.09a	0.02ab	0.01a	0.05a	0.18a	0.29a	0.01a	0.04a	0.33ab	0.02a
Freshwater1	G. Prairie	3030a	1.52ab	0.05a	0.05b	0.04a	0.01ab	0.01a	0.02a	0.10a	0.38a	0.05a	0.06a	0.80ab	0.09a
Freshwater2	G. Prairie	1730ab	1.80ab	0.02a	0.01b	0.03a	0.02ab	0.01a	0.01a	0.10a	0.20a	0.41a	0.13a	1.11ab	0.23a
Freshwater3	G. Prairie	535ab	0.64b	0.02a	0.02b	0.03a	0.01b	0.01a	0.01a	0.10a	0.16a	0.02a	0.09a	0.89ab	0.09a
Invert	Rocky Mtn.	245b	17.4a	0.02a	0.03a	0.04a	0.10b	0.01a	0.38a	0.14a	0.56a	0.10a	0.57a	0.39b	5.93a
Invert	G. Prairie	423a	15.8a	0.02a	0.02a	0.11a	0.14a	0.01a	0.15b	0.16a	0.38b	0.02b	0.29b	1.05a	2.44a
KCl	Cold Lake	1730a	3.22a	0.01a	0.07a	0.003b	0.001b	0.01a	0.005a	0.10a	0.26b	0.08a	0.40a	0.89a	0.43a
KCl	Waterton	1890a	4.98a	0.02a	0.02a	0.03a	0.02a	0.01a	0.06a	0.37a	2.40a	0.45a	2.01a	0.28b	0.09b
NaCl	Cold Lake	1180a	5.20a	0.01a	0.05a	0.003b	0.01b	0.01a	0.001a	0.10a	1.00a	0.02b	0.01b	0.07b	0.33a
NaCl	Slave Lake	681b	6.99a	0.04a	0.03a	0.03a	0.05a	0.01a	0.09a	0.01a	0.58a	0.16a	1.05a	1.10a	0.16a

continued...

Table 9. Concluded.

Waste	Location	P	Mo	Ni	Se	Co	Si	As	SAR
		(mg/L)							
Freshwater	Cold Lake	0.13b*	1.38a	0.03a	0.04b	0.01a	14.7a	0.12b	37.6b
Freshwater	Rocky Mtn.	0.37ab	0.82ab	0.03a	0.30a	0.01a	17.7a	0.14b	66.7b
Freshwater	Waterton	1.17a	1.38a	0.03a	0.36a	0.01a	7.42a	0.45a	279a
Freshwater1	G. Prairie	0.28ab	0.94ab	0.03a	0.30a	0.01a	12.6a	0.11b	74.3b
Freshwater2	G. Prairie	0.50ab	0.37b	0.08a	0.30a	0.03a	9.88a	0.17b	25.7b
Freshwater3	G. Prairie	0.31ab	0.60b	0.03a	0.30a	0.01a	3.72a	0.09b	50.2b
Invert	Rocky Mtn.	0.62a	0.14b	0.22a	0.30a	0.05a	2.45a	0.16b	9.22b
Invert	G. Prairie	0.34b	0.54a	0.07b	0.30a	0.03b	1.05b	0.25a	10.8a
KCl	Cold Lake	0.03b	1.59a	0.03b	0.03b	0.01a	4.88a	0.009b	33.9b
KCl	Waterton	0.67a	0.53b	0.27a	0.30a	0.02a	4.22a	0.03a	77.6a
NaCl	Cold Lake	0.08b	0.10a	0.03b	0.03b	0.01a	3.36a	0.003b	338a
NaCl	Slave Lake	0.67a	0.20a	0.05a	0.30a	0.01a	2.45a	0.11a	51.7b

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

the invert waste than the other waste types. Zinc levels were highest in the KCl and NaCl wastes.

4.2.3 DTPA Extractable Elements

The plant available fractions of the soil elements were estimated by DTPA extraction. The chelate extractable elements have been shown to correlate well with plant elements (Soltanpour and Workman 1981). Table 10 provides a comparison of the mean values for the DTPA extractable elements by location for each of the major waste types.

The DTPA extractable element levels varied between waste type and between individual locations for a specific waste. None of the wastes contained consistently higher or lower levels of the individual elements. For example, the NaCl waste contained the highest levels of Fe, Cu, Mn, Mg, Na, and B. The KCl wastes contained the highest levels of Cd, K, and Zn.

The variability shown raises the possibility of differential plant uptake of many of the elements from the different waste types.

4.2.4 Total Elemental Analysis

The total elemental analysis of the wastes is used to assess the potential for heavy metal and other trace element contamination. A comparison of the mean values for total elemental analysis by location for each of the waste types is presented in Table 11.

The invert wastes showed significant differences between locations for the smallest number of parameters measured whereas the freshwater gel wastes showed significant differences between locations for the largest number of parameters measured. The same trends were observed for the liquid wastes.

The total element levels varied between waste type with none of the wastes containing consistently higher or lower levels of the individual elements. The NaCl wastes contained the highest

Table 10. Comparison of the mean values by waste and by location of the DTPA–NH4HCO3 extract data for the solid phase samples.

Waste	Location	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo
									(ug/g)						
Freshwater	Cold Lake	15	179a*	0.25a	9.65ab	14.5abc	18.7ab	20.1a	193a	102a	2100ab	240b	3.51a	3.85b	1.60b
Freshwater	Rocky Mtn.	6	89.0a	0.25a	5.50bc	9.65c	24.1ab	5.71b	299a	58.1a	1470b	171b	0.25b	4.31b	0.29c
Freshwater	Waterton	15	168a	0.25a	9.72ab	24.8abc	37.1a	15.6ab	219a	61.7a	11100a	1180a	0.42b	2.83b	2.65a
Freshwater1	G. Prairie	15	189a	0.07b	6.57bc	11.2bc	12.9b	10.2ab	245a	71.3a	10400ab	296b	0.59b	9.44b	1.10bc
Freshwater2	G. Prairie	8	198a	0.07b	5.18c	30.5ab	32.5ab	6.10b	264a	91.8a	1950ab	218b	1.05b	67.3a	0.35c
Freshwater3	G. Prairie	4	202a	0.07b	11.5a	34.3a	16.5ab	16.7a	210a	77.7a	4800ab	347b	0.37b	9.57b	0.81bc
Invert	Rocky Mtn.	9	54.5b	0.25a	1.58a	3.17a	36.6a	1.81a	319a	95.7a	1610b	393b	0.69b	1.56a	0.25a
Invert	G. Prairie	11	95.0a	0.03b	2.19a	3.42a	9.06b	1.72a	273b	22.3b	2440a	523a	1.35a	0.78b	0.28a
KCl	Cold Lake	14	196a	0.28a	7.19a	9.50b	49.8b	14.5a	180a	91.2b	1910b	6500b	3.39a	2.70a	1.61a
KCl	Waterton	15	109b	0.25b	5.83b	34.1a	143a	9.68a	175a	181a	7120a	26700a	0.90b	2.76a	0.92b
NaCl	Cold Lake	15	171b	0.25a	5.17b	10.1b	21.0a	16.0b	133a	219b	20300a	89.8b	1.39b	5.55a	0.25b
NaCl	Slave Lake	10	299a	0.15b	17.1a	20.1a	18.5a	48.1a	195a	1130a	8670b	241a	7.30a	4.76a	0.44a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Waste	Location	Ni	Se
		(ug/g)	
Freshwater	Cold Lake	2.17ab	0.97a
Freshwater	Rocky Mtn.	1.60ab	0.75a
Freshwater	Waterton	1.08b	2.15a
Freshwater1	G. Prairie	1.54ab	1.43a
Freshwater2	G. Prairie	2.38a	0.75a
Freshwater3	G. Prairie	1.40ab	0.81a
Invert	Rocky Mtn.	0.39b	0.75a
Invert	G. Prairie	0.73a	0.75a
KCl	Cold Lake	2.76a	0.80b
KCl	Waterton	1.48b	1.03a
NaCl	Cold Lake	0.79b	0.80a
NaCl	Slave Lake	2.77a	2.31a

Table 11. Comparison of the mean values by waste and by location of the total elemental analysis data for the solid phase samples.

Waste	Location	N	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti
									(ug/g)					
Freshwater	Cold Lake	15	413a*	11000ab	14300ab	47200a	9200a	28.1b	107c	724bc	31.8a	56200ab	27200ab	2750bc
Freshwater	Rocky Mtn.	6	362a	4120c	10800b	6560b	2880b	32.2b	162abc	1100ab	32.2a	37500b	23500b	2720bc
Freshwater	Waterton	15	426a	13000a	15000ab	5070b	2210bc	46.4a	204a	488c	40.6a	55900ab	29800ab	2520c
Freshwater1	G. Prairie	15	365a	11400ab	15400a	6150b	2320bc	30.7b	127bc	1140ab	33.3a	43800ab	28500ab	3110abc
Freshwater2	G. Prairie	8	256a	6390bc	16400a	4570b	1870bc	31.5b	184ab	1550a	35.8a	55900ab	32800a	3980a
Freshwater3	G. Prairie	4	328a	9190abc	15800a	4620b	1450c	33.0b	136bc	926bc	37.0a	58170a	31100a	3440ab
Invert	Rocky Mtn.	9	169a	4600a	17500a	6370a	3180a	34.2a	216a	869a	34.1a	53000a	34200a	3740a
Invert	G. Prairie	11	188a	4400a	17000a	8200a	3440a	24.9b	145b	849a	26.1b	51300a	31800a	3540a
KCl	Cold Lake	14	393a	10100a	29900b	34300a	8610a	26.9b	183b	776a	31.0a	58000a	27500a	3060a
KCl	Waterton	15	314b	10100a	39600a	4910b	3080b	55.1a	502a	321b	32.2a	18700b	19300b	1660b
NaCl	Cold Lake	15	283b	45900a	11100a	56800a	13700a	12.6b	77.8a	397a	24.1a	35500a	16700b	1870a
NaCl	Slave Lake	10	525a	12100b	10700a	11000b	6110b	71.3a	84.7a	493a	16.6b	13400b	30300a	1870a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Waste	Location	V	Cr	Ba	Ni	Sr	Li	Zr
					(ug/g)			
Freshwater	Cold Lake	112bc	81.9b	848a	35.1a	211a	44.9abc	120a
Freshwater	Rocky Mtn.	82.8c	63.3b	305b	31.3a	146bc	29.4c	88.3a
Freshwater	Waterton	94.2c	224a	380b	55.6a	166ab	36.0bc	115a
Freshwater1	G. Prairie	136ab	134ab	602ab	36.7a	129bc	51.9ab	99.8a
Freshwater2	G. Prairie	160a	93.7b	637ab	43.4a	106c	59.6a	110a
Freshwater3	G. Prairie	145ab	108b	913a	31.8a	125bc	44.2abc	90.1a
Invert	Rocky Mtn.	180a	98.8a	151b	44.6a	152a	62.5a	92.4a
Invert	G. Prairie	180a	97.5a	464a	37.8a	151a	59.4a	86.7a
KCl	Cold Lake	132a	85.6a	666a	34.3a	211a	58.4a	129a
KCl	Waterton	57.6b	88.1a	984a	31.1a	349a	48.3b	71.3b
NaCl	Cold Lake	47.7a	60.6a	416a	19.7b	182a	48.2a	85.6a
NaCl	Slave Lake	71.2a	198a	222b	42.5a	97.3b	48.0a	46.2b

levels of Na, Ca, Mg, and Cu while the KCl wastes contained the highest levels of K, Sr, and Zn.

Values for the total elemental content of wastes in Table 11 were compared to the values for total elemental content of soils presented in Table 12 (Lindsay 1979) to assess any potential hazard to a receiving soil from the addition of the wastes. All the mean values for the various elements shown in Table 11 were within the range of values normally found in soils (Table 12) except for Na, K, Mg, Zn, and Mo. Maximum values for Na in soil were exceeded by some of the freshwater gel wastes and the KCl and NaCl wastes. Maximum values for Mg in soil were exceeded by the freshwater gel and KCl wastes from Cold Lake and both NaCl waste locations. Maximum values for Zn in soil were exceeded by the KCl waste from the Waterton location. Maximum values for Mo in soil were exceeded by all waste types from all sampling locations.

4.2.5 Mineralogy of the Solid Wastes

A number of minerals were identified in the wastes and the data are summarized in Table 13. Calcite ($CaCO_3$), quartz (SiO_2), and kaolinite were found in all of the wastes sampled. Barite ($BaSO_4$) was found in significant amounts in the invert waste from the Rocky Mountain House site and the freshwater and KCl wastes from the Waterton site. Dolomite ($CaMg(CO_3)_2$) was present in significant amounts in the KCl and NaCl wastes from the Cold Lake sites, the freshwater waste from the Grande Prairie site and the water (no additives) waste from the Rocky Mountain House site. Portlandite ($Ca(OH)_2$) was found in significant amounts in the DAP material.

Traces of illite were found in most of the wastes while the presence of montmorillonite appeared to be limited to the freshwater gel materials. Sylvite was detected in the KCl wastes.

The origin of the minerals such as barite, portlandite, and most of the clays are likely due mainly to addition from the drilling mud used initially. The calcite and dolomite are likely of geologic origin.

Table 12. Elemental constituents of soils.

Element	Mean	Maximum	Minimum	Element	Mean	Maximum	Minimum
C (%)	2.00			Li (μg/g)	20.00	200.0	5.000
Ca (mg/g)	13.70	500.0	7.000	Cr (μg/g)	100.00	1000.0	1.000
Mg (mg/g)	5.00	6.0	0.600	Cu (μg/g)	30.00	100.0	2.000
Ti (mg/g)	4.00	10.0	1.000	Hg (μg/g)	0.03	0.3	0.010
Na (mg/g)	6.30	7.5	0.750	Ni (μg/g)	40.00	500.0	5.000
S (mg/g)	0.70	10.0	0.030	Pb (μg/g)	10.00	200.0	2.000
P (mg/g)	0.60	5.0	0.200	Co (μg/g)	8.00	40.0	1.000
Sr (mg/g)	0.20	1.0	0.050	Mo (μg/g)	2.00	5.0	0.200
Al (mg/g)	71.00	300.0	10.000	Cd (μg/g)	0.06	0.7	0.010
Si (mg/g)	320.00	350.0	230.000	Se (μg/g)	0.30	2.0	0.100
B (mg/g)	0.01	0.1	0.002	Ag (μg/g)	0.05	5.0	0.010
Ba (mg/g)	0.43	3.0	0.100	Zn (μg/g)	50.00	300.0	10.000
Fe (mg/g)	38.00	550.0	7.000	V (μg/g)	100.0	500.0	20.000
K (mg/g)	8.30	30.0	0.400	As (μg/g)	5.00	50.0	1.000
Mn (mg/g)	0.60	3.0	0.020	Zr (μg/g)	300.0	2000.0	60.0

From Lindsay (1979).

Table 13. Mineralogy of the solid phase sump samples.

	Freshwater Gel				DAP	Invert		KCl		NaCl		Water (NA)[d]
	Cold Lake	Water-ton	Rocky Mtn. House	Grande Prairie	Cold Lake	Rocky Mtn. House	Grande Prairie	Cold Lake	Water-ton	Cold Lake	Slave Lake	Rocky Mtn. House
Barite	-	x[a]	-	-	-	x	-	-	x		-	-
Calcite	x	t[b]	t	x	x	t	t	x	t	x	x	x
Dolomite	t	-[c]	-	x	-	-	-	x	-	x	-	x
Gypsum	-	-	-	-	-	-	-	-	-	-	x	-
Feldspars	x	-	-	t	-	-	t	x	-	x	t	t
Portlandite	-	-	-	-	x	-	-	-	-	-	-	-
Pyrite	-	-	-	t	-	-	x	-	-	-	-	-
Quartz	x	x	x	x	x	x	x	x	x	x	x	x
Chlorite	t	t	-	t	-	-	-	-	-	-	-	t
Halite	-	-	-	-	-	-	-	-	-	x	x	-
Kaolinite	t	t	t	t	t	t	t	t	t	t	t	t
Illite	t	t	t	t	-	-	t	t	-	-	t	t
Montmorillonite	t	t	-	-	-	-	-	-	-	-	-	t
Sylvite	-	-	-	-	-	-	-	t	t	-	-	-

[a] x = Mineral present in significant amounts.

[b] t = Mineral present in trace amounts.

[c] - = Mineral not present.

[d] NA = No additives.

4.2.6 Oil Separation Characteristics

Oily materials have been shown to contain a variety of organic compounds that vary in structure and degree of susceptibility to degradation and volatilization (Connell and Miller 1981a). Oils are mixtures of n- and iso-alkanes, cycloalkanes, aromatic hydrocarbons, and various S, N, and O compounds (Connell and Miller 1981a). Several of the oil fractions such as polynuclear aromatic hydrocarbons (PAH), methyl derivatives of polycyclic and heterocyclic compounds, and nitrogen and sulphur derived heterocyclics are known or suspected mammalian and human carcinogens (Connell and Miller 1981b). A preliminary identification of the organic compounds found in the oils extracted from the drilling waste samples was done to assess the nature of the oil fractions and their potential environmental impact when and if these wastes are landspread.

The effect of oil addition to soil is dependent on the amount added, soil type, moisture, and temperature (Overcash and Pal 1979). Additions of oil to soil at about 1% of soil weight leads to observed effects on plant yields, and at 1.5 to 2% the reduction of yield is substantial ranging to 50% (Overcash and Pal 1979). In Alberta, Toogood (1977) reported reductions in hay stands of 10, 23, 35, and 48% three years after additions of light oil at 0.7, 1, 1.3, and 2% of soil by weight respectively. Complete restoration of barley yields was observed after one year for an oil addition of 20 gal/150 sq ft (90 L/15 m^2), after three years for oil at 50 gal/150 sq ft (270 L/15 m^2), and after five years for oil at 90 gal/150 sq ft (400 L/15 m^2) (Toogood and McGill 1977). Another concern regarding oil addition to soil is the presence in the oil itself of polynuclear aromatic hydrocarbons (Fuller and Warrick 1985; Rowell 1977).

The oily materials contained in the samples obtained were generally well mixed with the wastes and in very few cases found in separate agglomerates or "clumps". Oil was extracted from the solid wastes by methylene chloride soxhlet extraction, and the extract analysed for oil content. To facilitate the speciation of the methylene chloride extract, it was extracted further into acid, base and neutral fractions. The above procedure was completed for a composite sample of the solid materials from each sump sampled. Because the results were similar for all wastes with very little variation between sumps, detailed data for KCl waste from the Cold Lake area were selected for presentation.

Organic compounds were not evident in the acid or base fractions (Figures 13 and 14), but concentrated in the neutral fraction (Figure 15).

The GC-MS scan of the organic compounds in the neutral fractions (Figure 15) showed the presence of unresolved hydrocarbons whose mass spectra were indicative of both aromatic and aliphatic compounds. A comparison of the GC-MS scan of the neutral fraction (Figure 16) to that of the scan positions of several compounds indicated the presence primarily of open chain saturates from C_{14} to C_{23} (Figure 16) with the greatest concentration from C_{15} to C_{20}, 1-ring (Figure 17) and 2-ring saturates (Figure 18). These compounds were also prevalent in the hexane eluted fraction of the neutral extracts.

Fractionation of the neutral extracts on a neutral alumina column according to a modified procedure of Later et al. (1981) indicated the presence of alkanes eluted with hexane, neutral and possibly nitrogen polyaromatic hydrocarbons eluted with benzene, and mostly aliphatic compounds eluted with both methylene chloride and acetonitrile.

The benzene eluted fraction of the neutral extract was studied further and its GC-MS scan is shown in Figure 19. The presence of the following organic compounds and their series was indicated in this benzene fraction for all the wastes studied: pyrenes, benzofluorenes and bezocycloparaffins (Figure 20); fluorenes (Figure 21); dibenzothiophenes and naphthalenes (Figure 22); phenanthrenes and anthracenes (Figure 23); alkylbenzenes and phenanthro-cycloparaffins (Figure 24). A comparison of all the above

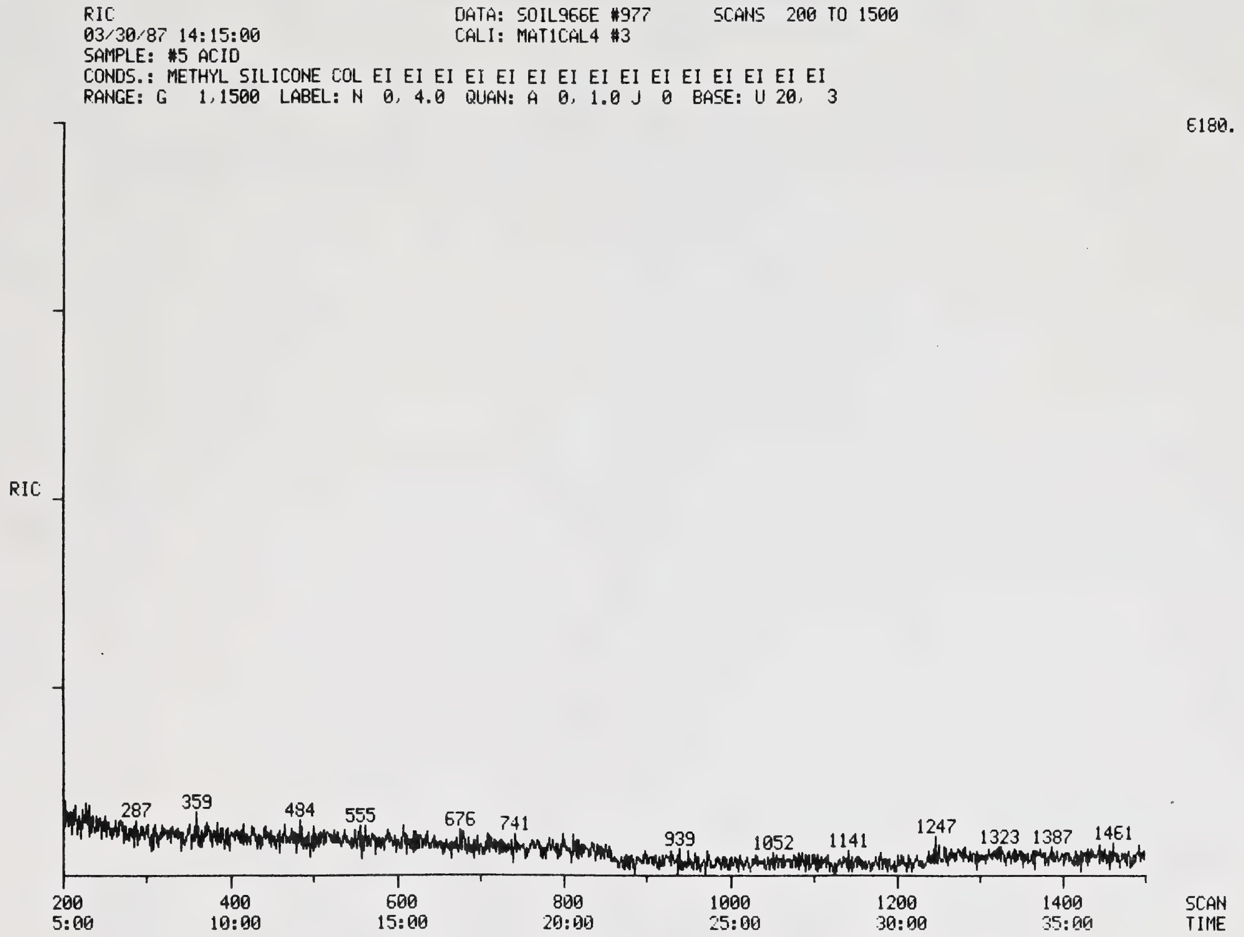


Figure 13. GC-MS scan of the acid extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

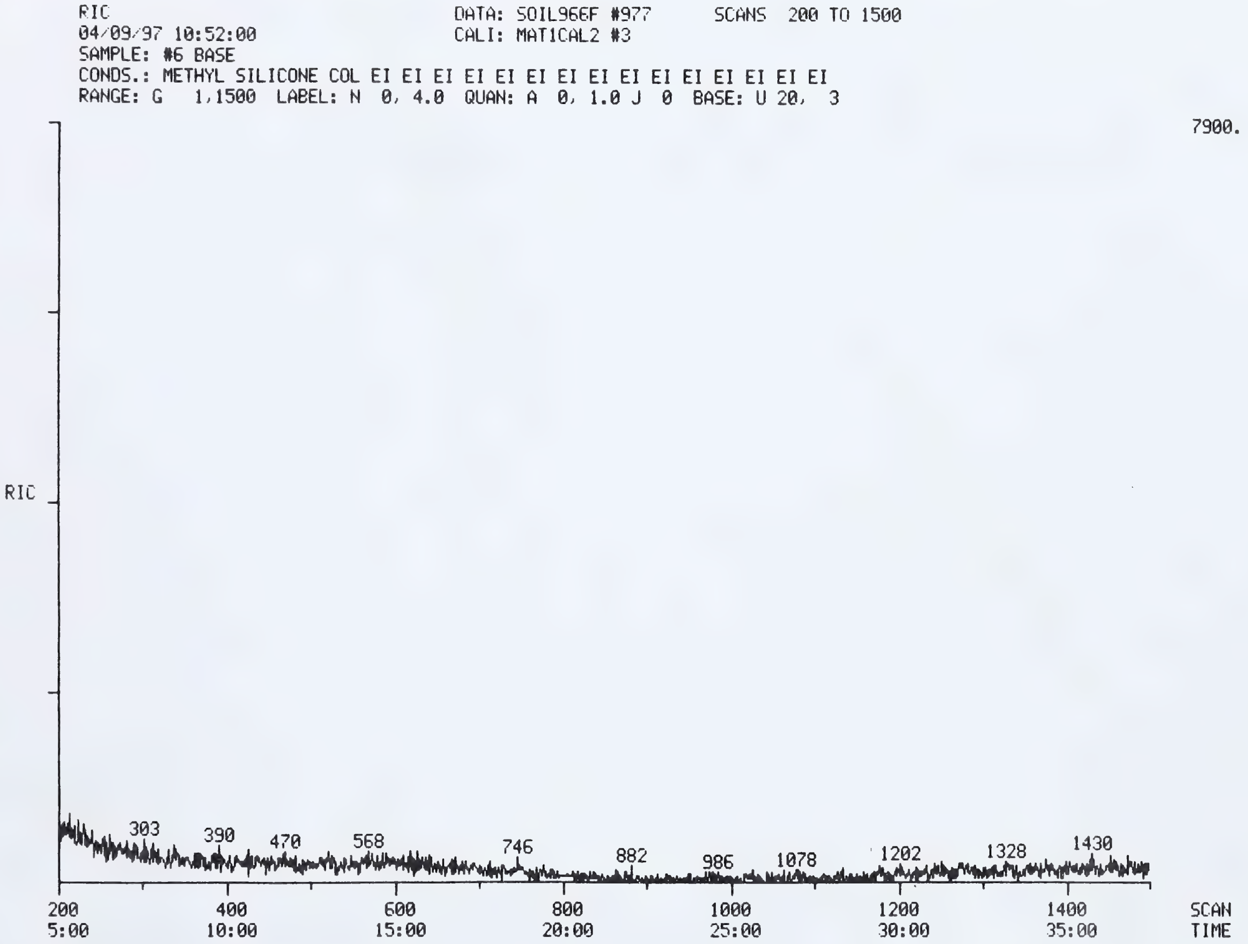


Figure 14. GC-MS scan of the base extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

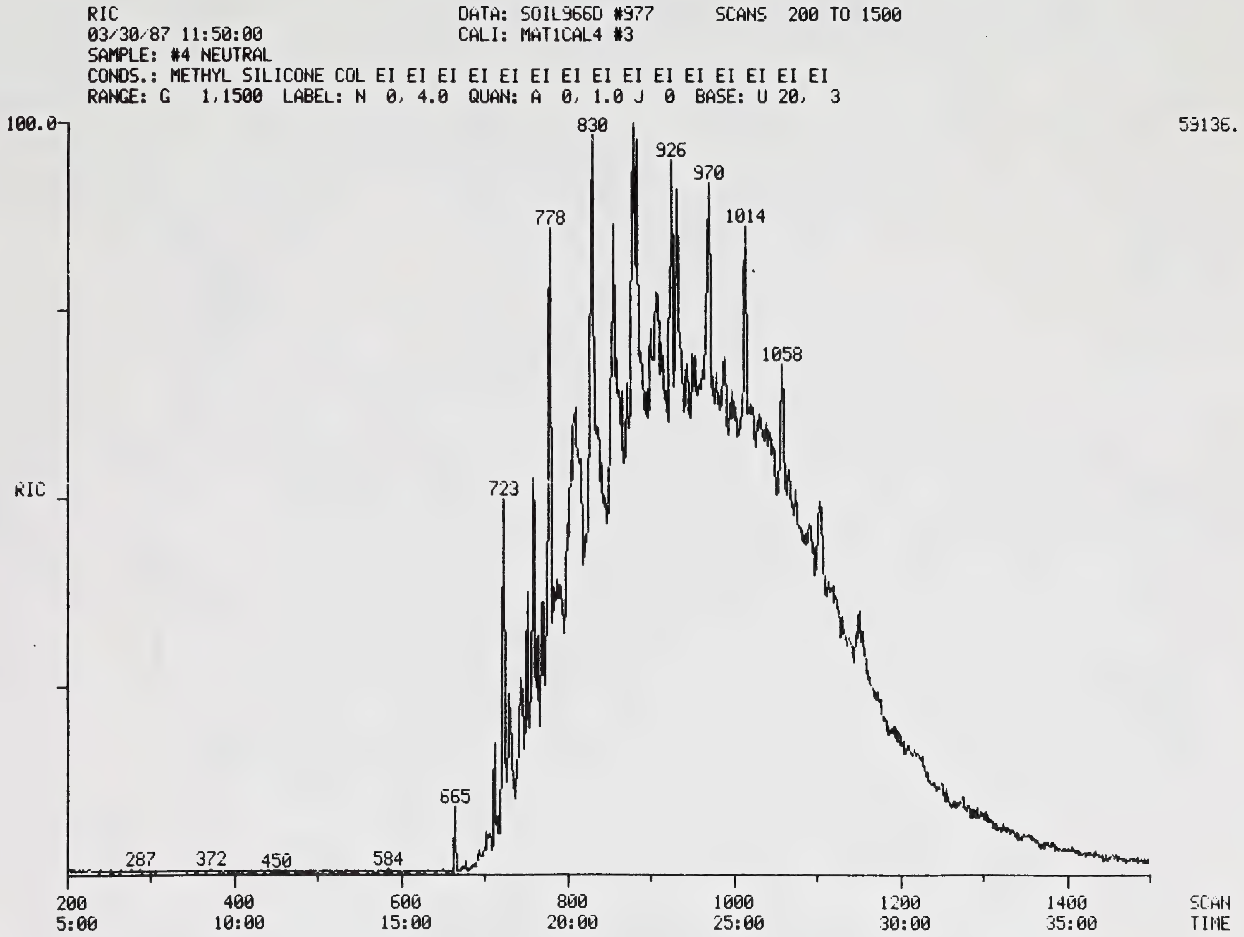


Figure 15. GC-MS scan of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

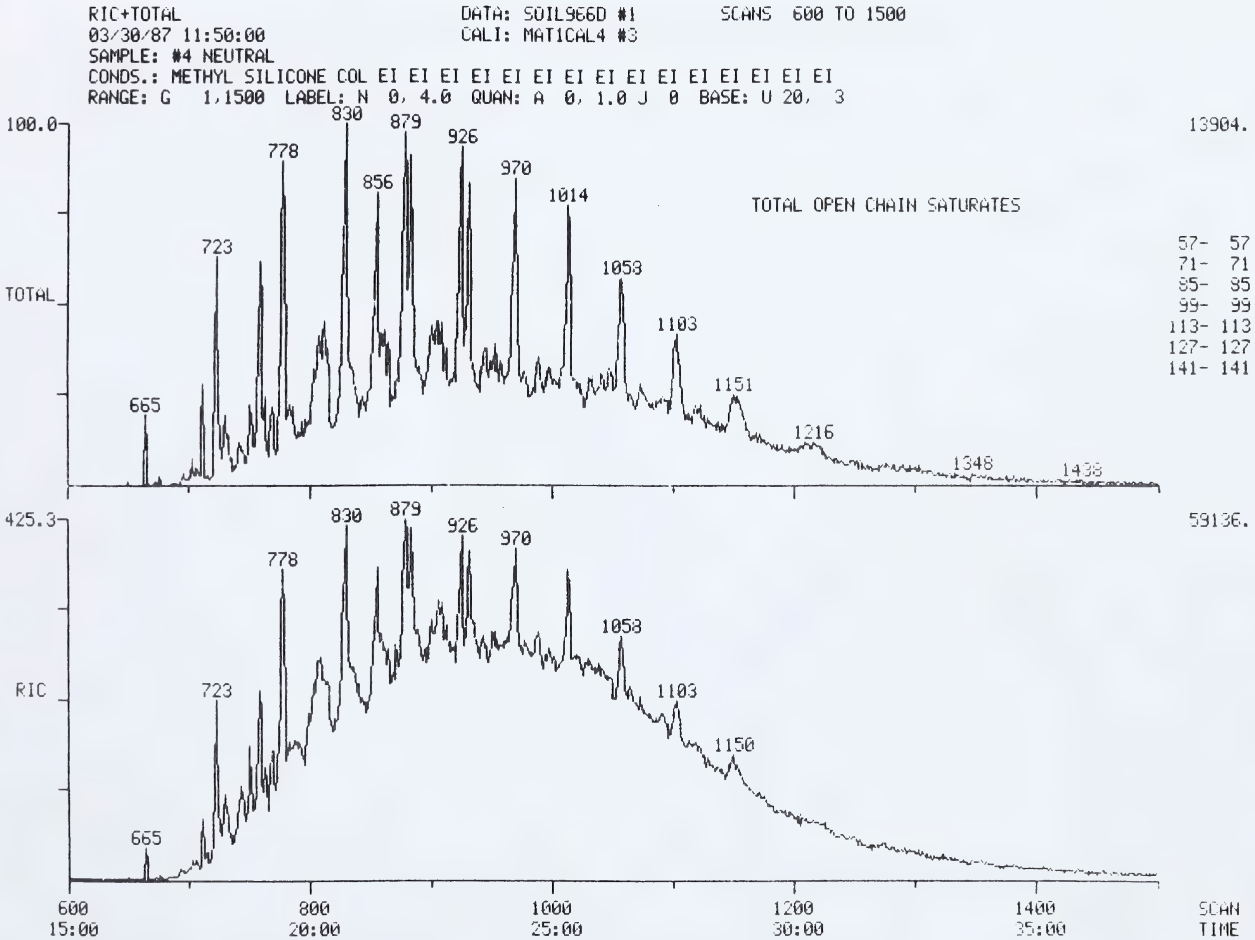


Figure 16. Comparison of the sum of the total open chain saturates with the GC-MS scan of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

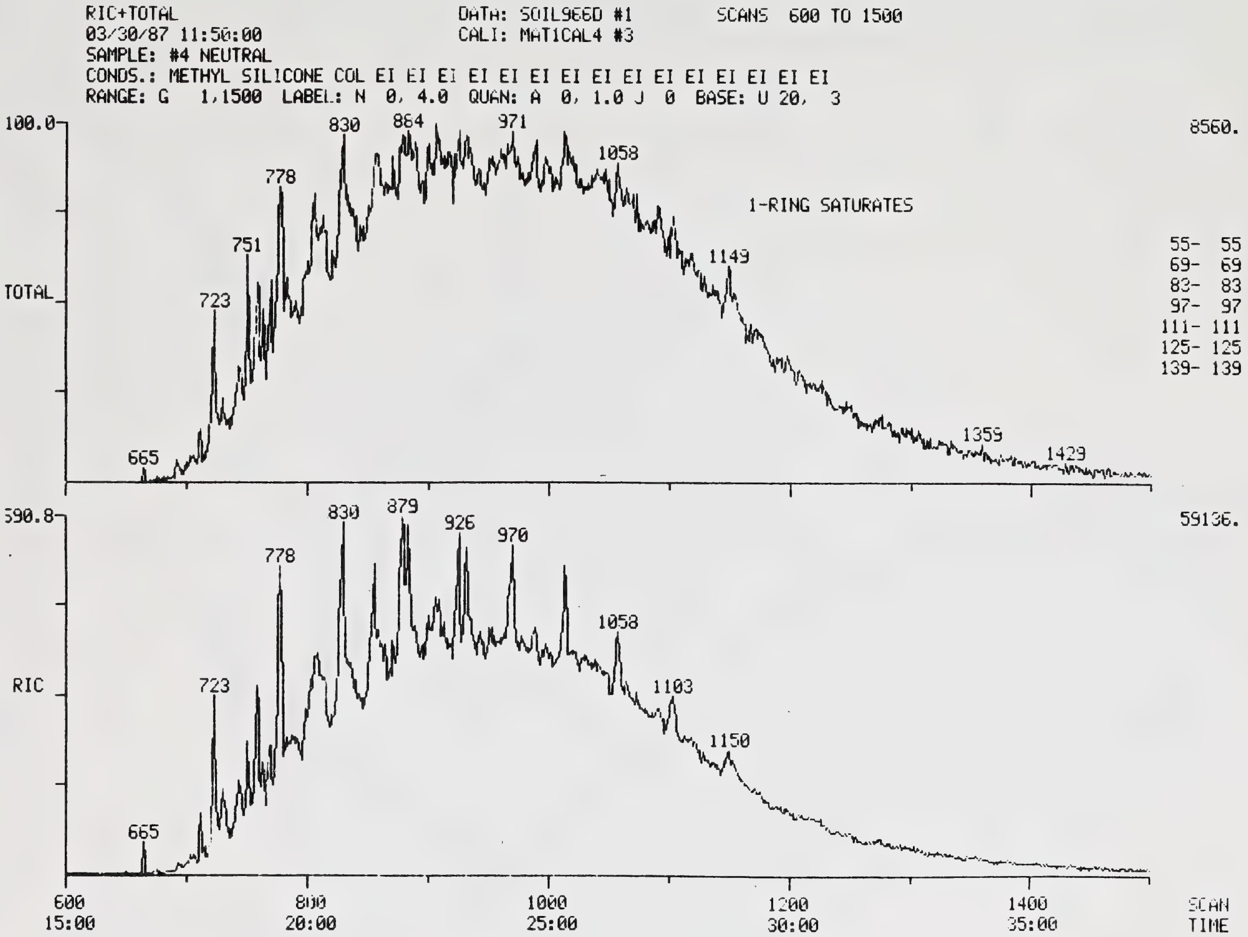


Figure 17. Comparison of the sum of the 1-ring saturates with the GC-MS scan of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

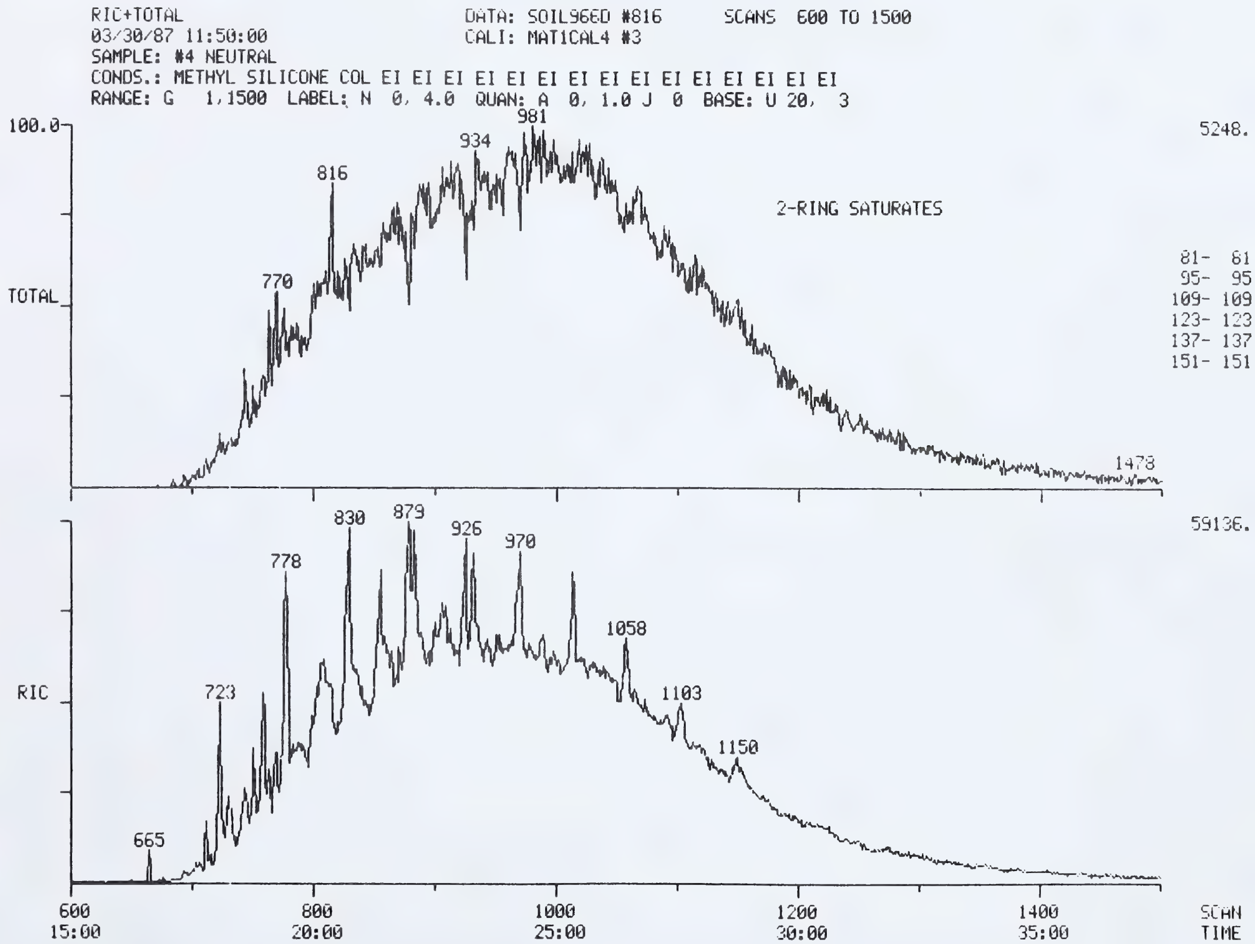


Figure 18. Comparison of the sum of the 2-ring saturates with the GC-MS scan of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

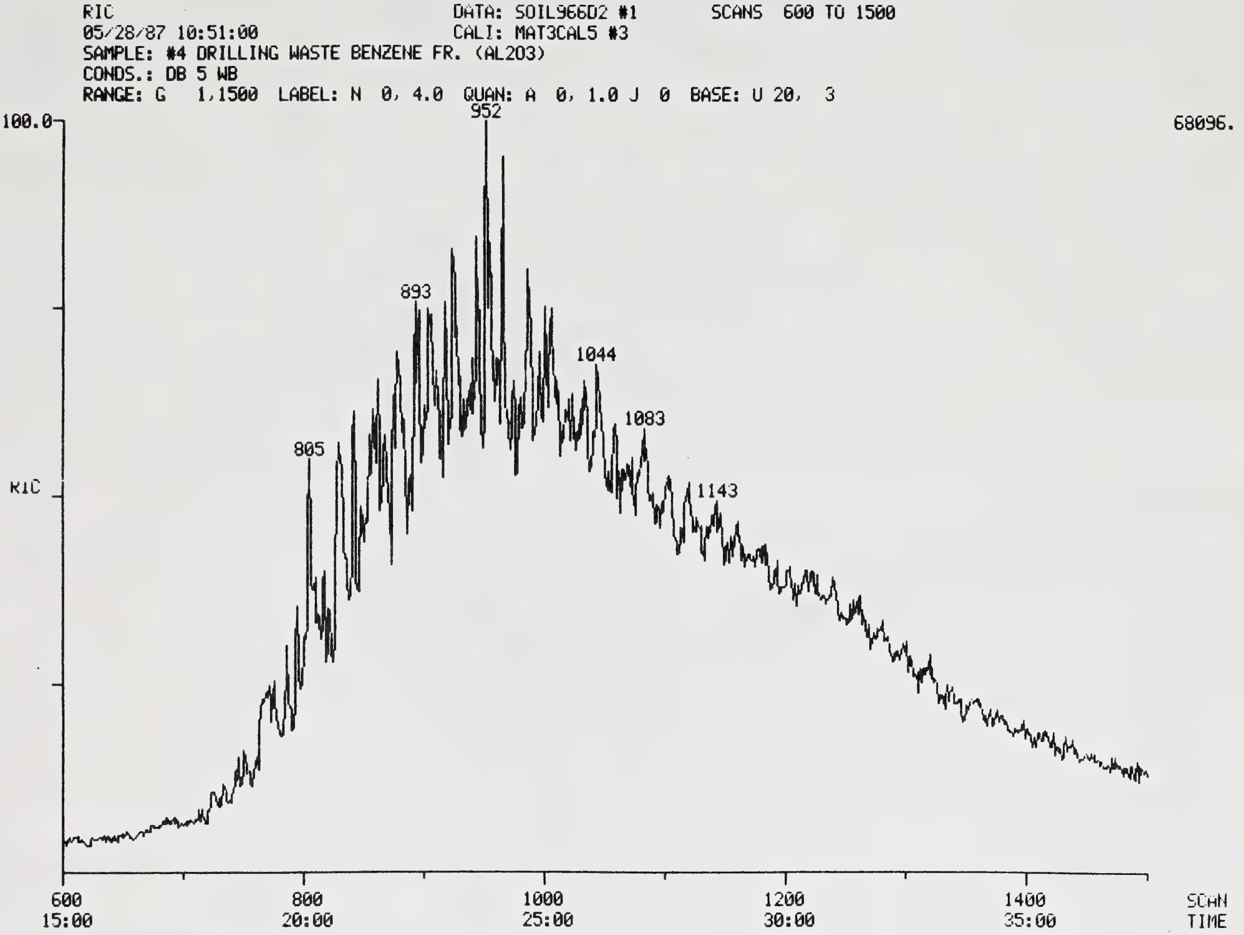


Figure 19. GC-MS scan of the benzene eluted fraction from an alumina column of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

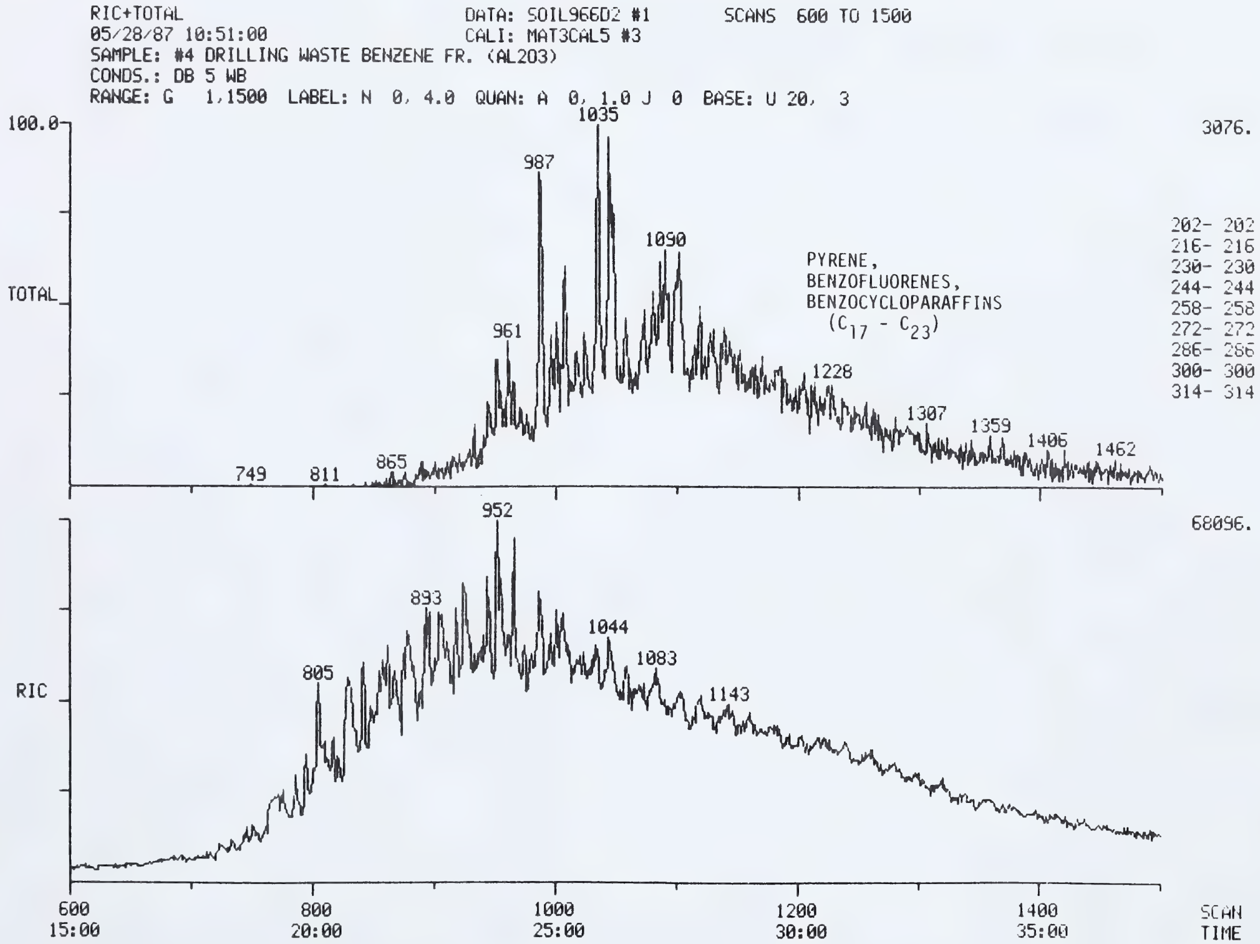


Figure 20. Comparison of the sum of the total benzocycloparaffins (C_{17}-C_{23}), pyrenes and benzofluorenes with the GC-MS scan of the benzene eluted fraction of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

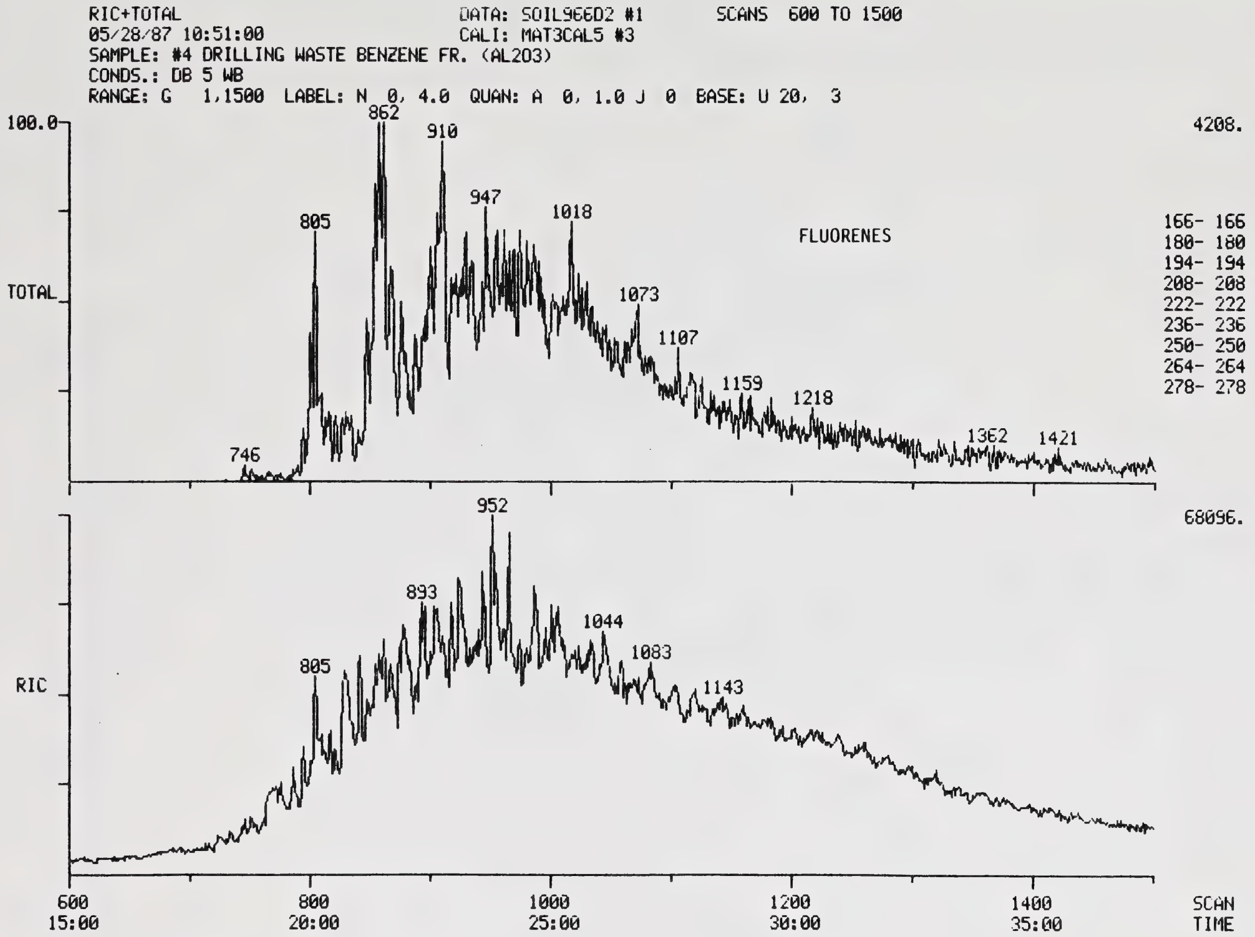


Figure 21. Comparison of the sum of the total fluorenes with the GC-MS scan of the benzene eluted fraction of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

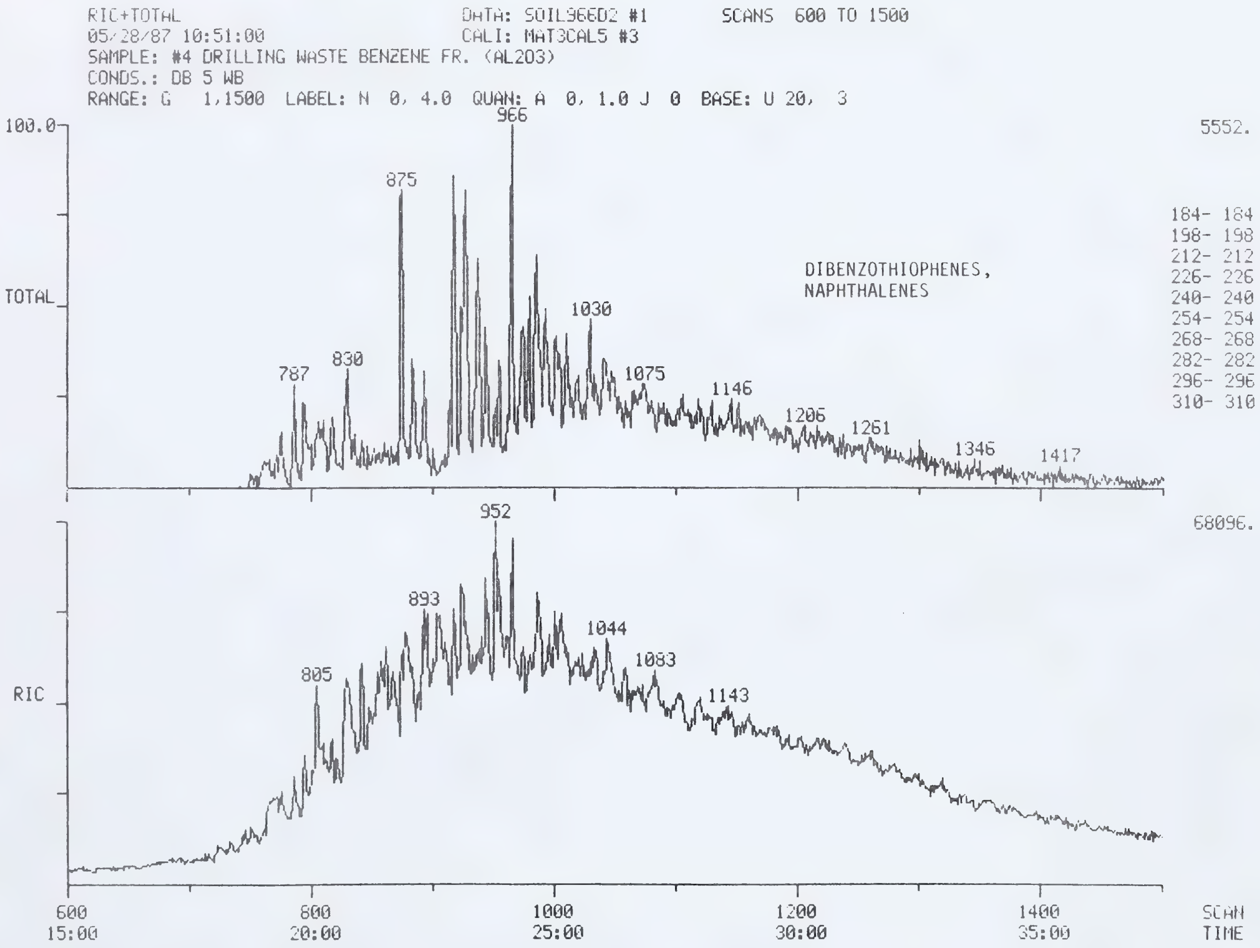


Figure 22. Comparison of the sum of the total dibenzothiophenes and naphthalenes with the GC-MS scan of the benzene eluted fraction of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

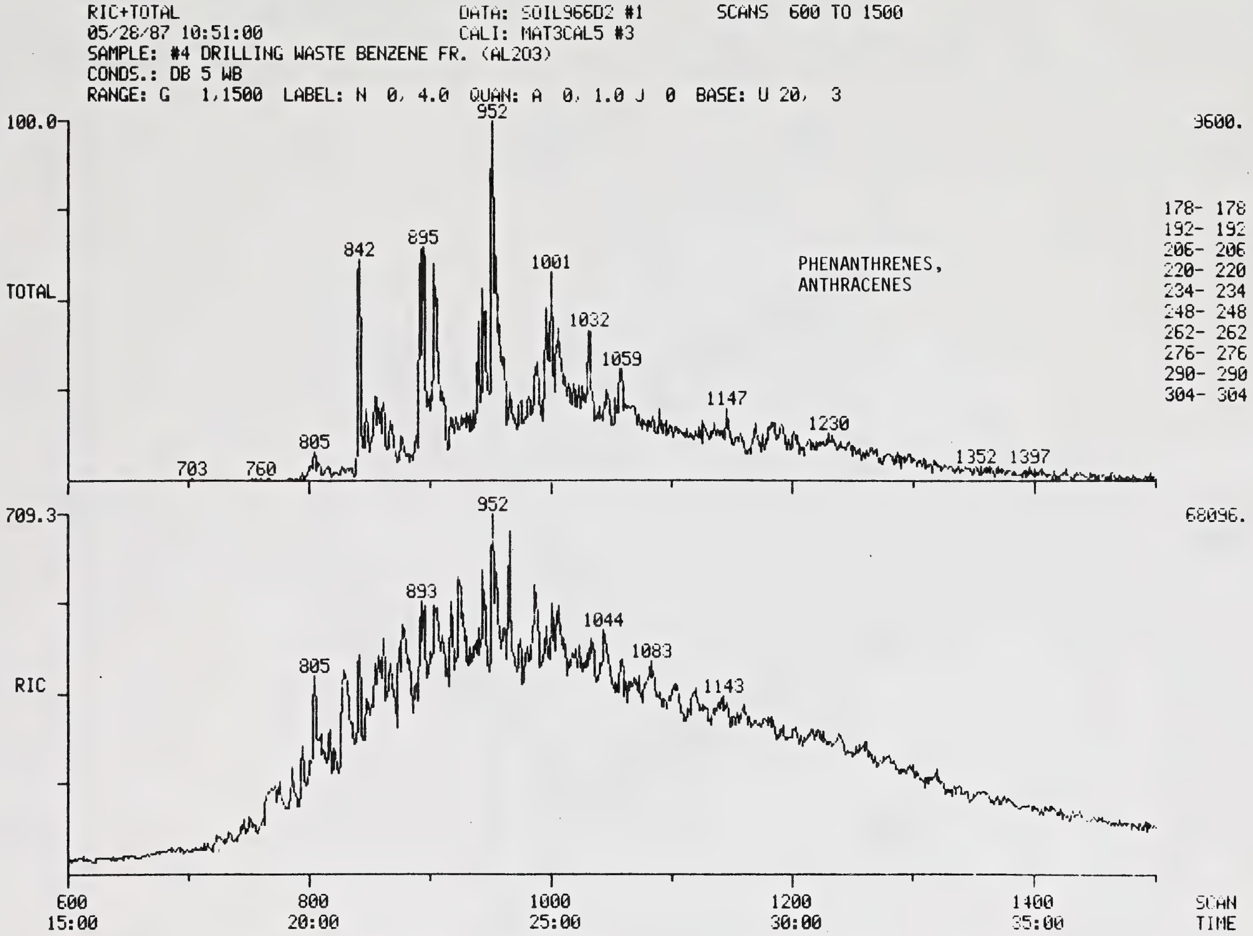


Figure 23. Comparison of the sum of the total phenanthrenes and anthracenes with the GC-MS scan of the benzene eluted fraction of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

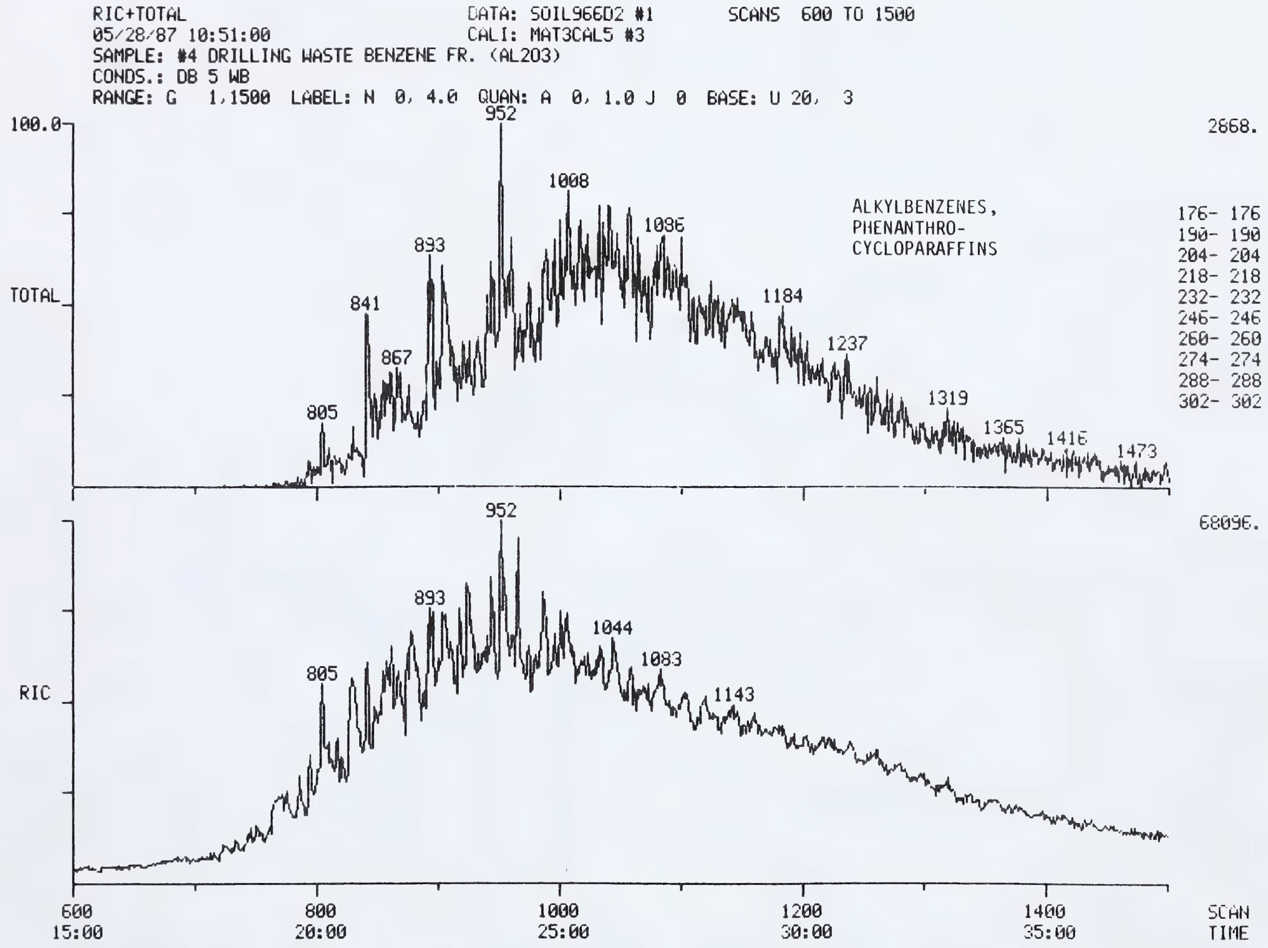


Figure 24. Comparison of the sum of the total alkylbenzenes and phenanthro-cycloparaffins with the GC-MS scan of the benzene eluted fraction of the neutral extracts of the methylene chloride extracted oil from a composite sample of the Cold Lake KCl waste.

series with the benzene fraction indicates that these series comprise most of the benzene fraction.

The methylene chloride and acetonitrile eluted fractions of the neutral extract did not produce a chromatogram. Infra-red and nuclear magnetic resonance spectra of these fractions ruled out the presence of aromatic or olefinic materials, but indicated the presence of alcohol, ketone and/or aldehyde groups.

The presence of the alkanes and the polyaromatic hydrocarbons in the wastes is indicative of the slow weathering of the oily waste materials in the sumps, possibly because of the reduced exposure to air of the organic compounds. Slow weathering rates were reported by MacKay (1975) who studied oil degradation in the subsurface or below the overlying organic detritus in the Norman Wells area and found weathering rates that are 10^2 to 10^3 times lower than on the surface. Duffy et al. (1975) found much lower weathering rates in the areas below 15 cm of soil both in Alberta spill areas and in laboratory studies. The presence of neutral organic compounds (PAH's) in the wastes might enhance the downward movement of these materials in the soil column. The implications of the neutral PAH movement below the soil surface are related to the quality of the groundwater and surface water resources. Duffy et al. (1975) reported that the movement of water soluble oil components and subsequent low weathering below the ground surface are severe threats to drinking water quality, and that it takes more than a 100 years of leaching by rainfall to bring the water to drinking quality standards.

4.3 ANALYSIS OF SAMPLING DESIGN

Heterogeneity in the landscape has been recognized for some time and its contribution to the variability of measured parameters has been the subject of many studies (Cline 1944; Reed and Rigney 1947). Sampling variability has been studied for purposes of agricultural soil testing (Cameron et al. 1971; Leo 1963; McIntyre

1967), environmental effects research (Smith et al. 1987), sediments in aquatic environments (Hakanson 1984), and drilling-mud reserve pits (Wojtanowicz et al. 1989).

Assessment of the variability in the drilling waste properties is necessary for the proper interpretation of measured results. The confidence one has in the results is dependent on the sampling strategy used and the measured variables. To conserve resources and minimize costs, one needs to collect as few samples as needed for analysis. The minimum number of samples needed to gain a certain measure of confidence in the results has been estimated using normal classical statistics (Snedecor and Cochran 1962). Most studies on sampling have used the normal distribution for the population of samples in the field (Cameron et al. 1971; Cline 1944; Reed and Rigney 1947; Smith et al. 1987). According to classical statistical theory of sampling, the minimum number of samples needed to characterize variability depends on the standard deviation of the sample population, the acceptable tolerance in the data (variation from the mean) and on the confidence limits desired (t-value, Student t distribution at n-1 degrees of freedom and a probability of x). Smith et al. (1987) derived the number of samples (N) needed as:

$$N = (ts/d)^2$$

where N = minimum number of samples needed,
t = t value at n-1 d.f. and probability of x,
s = standard deviation,
d = largest acceptable difference between the estimate and mean.

Substituting the coefficient of variation C.V. ((s/mean)*100) and accuracy level A ((d/mean)*100) in the above equation yields:

$$N = t^2 \, (C.V./A)^2$$

which is the equation that can be used to calculate the minimum number of samples needed to characterize the variable with accuracy A(% of the mean) and confidence level (probability of x).

To assess the validity of the sampling scheme employed in this study, two statistical analyses were used. Firstly, the mean values of the samples sorted by depth and horizontal position were compared using the Tukey studentized range test (SAS 1985) to determine the effect of sampling by either depth or horizontal position. Secondly, the minimum number of samples needed to properly characterize the sludge's properties was estimated.

4.3.1 Comparisons Relative to Depth and Horizontal Position

The mean values of the samples sorted by depth and horizontal position were compared using the Tukey studentized range test at the 0.01 significance level (SAS 1985) to assess the validity of the sampling scheme.

4.3.1.1 Liquid phase wastes. Comparison of the means relative to depth and horizontal position for the liquid wastes are shown in Appendices 10.1 and 10.2. The data relative to depth indicated significant differences for some parameters associated with the freshwater gel and invert materials from the Grande Prairie area, the KCl material from the Waterton location and the NaCl liquid samples from the Cold Lake and Slave Lake areas. The horizontal position analysis indicated no significant differences between the five positions (hole numbers) for the analytical variables relative to all freshwater gel, invert, KCl and NaCl (Cold Lake) wastes. Some differences were detected for the NaCl waste from the Slave Lake (Red Earth Creek) area. This is likely due to the fact that this sump contained both NaCl and freshwater gel wastes.

The above analysis indicates that for the liquid phase in general, horizontal position, or number of discrete sample locations is insignificant. Depth was more significant but again only for some parameters in some of the wastes. It is interesting to note that the largest amount of variability in the liquid samples by depth occurred in the freshwater gel (Site 2) sump from the Grande Prairie area. This sump was sampled shortly after the termination of drilling activity.

These data suggest that compositing of the samples from various locations or horizontal positions on the basis of depth would have been adequate to characterize the liquid wastes sampled in this study.

4.3.1.2 Solid phase wastes.

4.3.1.2.1 Chemical and physical properties. Comparisons of the means relative to depth and horizontal position for some chemical and physical properties of the solid phase waste samples are presented in Appendices 10.3 and 10.4. Depth was not a factor for any of the freshwater gel or invert sumps sampled. Depth was a factor for the total carbon and total organic carbon in the DAP waste and extractable K in the KCl waste from the Waterton site. Significant differences in CEC and extractable Ca, K, and Mg occurred relative to the NaCl wastes from the Cold Lake area.

Horizontal position was not a factor for the invert and KCl solids. The parameters including pH($CaCl_2$), ANC, lime equivalent and extractable Ca, K, and Mg were significantly different by depth for the DAP waste. The freshwater gel wastes exhibited significant differences in pH($CaCl_2$) ANC, lime equivalent, total inorganic and total organic carbon by depth.

In general there was very little difference between depth and horizontal position for most of the physical and chemical parameters measured.

4.3.1.2.2 Saturated paste extract data. Comparisons of the means relative to depth and horizontal position for the saturated paste extract data are provided in Appendices 10.5 and 10.6. The data show no significant differences between depths for the invert waste.

Differences by depth for the freshwater gel waste occurred only in the material from the Rocky Mountain House site and involved the parameters of Ba, Cu, Mn, Pb, and Ti. The KCl waste from the Cold Lake area had differences in EC, Cl, Na, and K by depth. The NaCl waste from the Slave Lake area exhibited differences by depth for Cr, Cu, Fe, and Na.

Horizontal position means were different for EC, pH, HCO_3, Cl, Al, As, Mo, and V in the DAP waste. The freshwater gel waste from Grande Prairie had differences in Cl, Co, and Mg. The only difference in invert waste was associated with barium for the material from Rocky Mountain House. Aluminum, B, Ba, and Li were different for the KCl waste from Cold Lake. Boron and P were different for the NaCl waste from Cold Lake and Mg and Si were different in the NaCl waste from Slave Lake.

4.3.1.2.3 DTPA extractable elements. Comparisons of the means relative to depth and horizontal position for DTPA extractable elements are presented in Appendices 10.7 and 10.8. The only significant differences that occurred by depth include Na and K in the KCl waste from the Waterton site and Cu, K, Mg, Pb, and Zn in the NaCl waste from the Cold Lake site.

The data show no significant differences between horizontal positions for the invert wastes. Horizontal position means were different for Ca, Cu, Fe, Mo, and Ni in the DAP waste and Ca, Mg, Mn, Na, Se, and Zn in the freshwater waste from the Cold Lake site. Horizontal position means were different for Ca, Cu, Fe, K, Mg, Mn, and P in the KCl waste from the Cold Lake site and Mn, Ni, and P in the NaCl waste also from the Cold Lake site.

4.3.1.2.4 Total elemental analysis data. Comparisons of the means relative to depth and horizontal position for the total elemental analysis data are presented in Appendices 10.9 and 10.10.

The only significant difference that occurred by depth was Ca in the NaCl waste from the Slave Lake site. Differences by horizontal position included Al, Mg, Na, and Ti in the DAP waste and Ba, K, Mo, and Zn in the invert waste from the Rocky Mountain House site. Horizontal position means were different for Cr, Li, Ni, Zn, and Zr for the freshwater gel wastes from the Cold Lake site and Mn, P, and Zn in the freshwater gel wastes from the Grande Prairie sites. Horizontal position means were different for Al, Fe, Mn, P, Ti, V, and Zr in the KCl wastes from the Waterton site and Cu and Zr for NaCl wastes from the Cold Lake site.

4.3.2 Number of Samples Required

Statistical analysis of the data pertinent to all wastes from all sites was completed for the preparation of reports pertinent to the three regions sampled (Macyk et al. 1987a, 1988, 1989). Using the reported means and standard deviations, the coefficient of variation (CV) and the number of samples needed to characterize the respective wastes were calculated for each analytical parameter determined with an accuracy of 10 or 20% of the mean at a probability of 0.05.

4.3.2.1 Liquid phase wastes. The number of samples required to characterize the liquid phase wastes is presented in Tables 14 and 15. The number of samples required to determine pH was relatively low ranging from one to ten depending upon waste type. The range was somewhat broader for the remaining parameters particularly some of the trace elements. The low levels of the trace elements (often close to the instrument detection limit) is likely the cause of high CV values and hence the large number of samples needed.

4.3.2.2 Solid phase wastes.

4.3.2.2.1 Chemical and physical properties. The number of samples required to characterize the solid phase wastes using physical and chemical properties is presented in Tables 16 and 17. The number of samples required ranges from 1 to 1059 at the 10% confidence level

Table 14. Number of samples required to characterize the freshwater gel liquid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean).

Variable	RM* 10%	RM 20%	GP1 10%	GP1 20%	GP2 10%	GP2 20%	GP3 10%	GP3 20%	CL 10%	CL 20%	WAT 10%	WAT 20%
pH	8	2	6	2	19	5	2	1	1	1	2	1
E.C. (ds/m)	92	23	1476	369	187	47	124	31	1	1	53	13
Alkalinity	359	90	271	68	356	89	71	18	1	1	35	9
HCO3	145	36	230	58	149	37	60	15	1	1	24	6
CO3	4887	1222	2915	729	750	188	1755	439	29	7	1506	376
OH	3747	937	3757	939	590	148	1225	306	30	7	1418	354
Cl	91	23	585	146	235	59	193	48	5	1	36	9
Al	496	124	998	250	443	111	2966	742	99	25	2439	610
Cr	BD	BD	932	233	352	88	582	145	BD	BD	630	158
Fe	BD	BD	173	43	429	107	2022	505	7	2	1190	298
V	BD	BD	BD	BD	398	99	BD	BD	BD	BD	158	39
Ti	963	241	537	134	422	105	906	227	83	21	1929	482
Cd	BD	BD	BD	BD	21	5	BD	BD	BD	BD	BD	BD
Cu	2166	541	51	13	99	25	26	7	BD	BD	BD	BD
Pb	BD	BD	BD	BD	331	83	BD	BD	BD	BD	BD	BD
Zn	428	107	1657	414	301	75	280	70	BD	BD	70	18
Mn	6845	1711	426	107	396	99	158	39	BD	BD	232	58
Ca	213	53	195	49	105	26	90	22	10	3	222	55
Mg	2767	692	126	31	381	95	118	30	43	11	215	53
Na	28	7	2087	522	229	57	245	61	1	1	26	7
K	73	18	792	198	370	92	119	30	4841	1210	14	4
Li	428	107	BD	BD	71	18	1	1	BD	BD	BD	BD
Sr	221	55	1339	335	259	65	25	6	BD	BD	123	31
B	293	73	497	124	357	89	28	7	BD	BD	21	5
Ba	233	58	699	175	468	117	107	27	BD	BD	105	26
P	780	195	151	38	458	115	420	105	BD	BD	280	70
Mo	BD	BD	796	199	154	38	48	12	BD	BD	966	241
Ni	241	60	BD	BD	73	18	BD	BD	BD	BD	BD	BD
Se	BD	BD	BD	BD	200	50	BD	BD	BD	BD	BD	BD
Co	BD	BD	BD	BD	104	26	25	6	BD	BD	BD	BD
As	347	87	909	227	159	40	62	15	24	6	20	5
S	32	8	3011	753	192	48	127	32	1	1	75	19
Si	13	3	154	39	451	113	460	115	2	1	838	209

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * RM – Rocky Mountain House; GP1 – Grande Prairie (Site 1); GP2 – Grande Prairie (Site 2); GP3 – Grande Prairie (Site 3); CL – Cold Lake Site; WAT – Waterton Site; BD = Elements below detection limit.

Table 15. Number of samples required to characterize the DAP, invert, KCl and NaCl liquid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean).

Variable	DAP* 10%	DAP 20%	IV1 10%	IV1 20%	IV2 10%	IV2 20%	KCl1 10%	KCl1 20%	KCl2 10%	KCl2 20%	NaCl1 10%	NaCl1 20%	NaCl2 10%	NaCl2 20%
pH	1	1	10	3	2	1	1	1	4	1	10	2	9	2
E.C. (ds/m)	2	1	130	33	30	7	1	1	2	1	306	76	57	14
Alkalinity	6	2	67	17	10	3	1	1	4	1	342	85	215	54
HCO3	6	2	124	31	11	3	1	1	8	2	291	73	195	49
CO3	4	1	3231	808	455	114	28	7	3085	771	1413	353	2035	509
OH	BD	BD	4654	1164	531	133	28	7	3938	984	2178	544	1532	383
Cl	3	1	456	114	62	16	1	1	1	1	284	71	61	15
Al	214	54	1020	255	24	6	BD	BD	51	13	BD	BD	143	36
Cr	11	3	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Fe	15	4	BD	BD	275	69	BD	BD	178	45	BD	BD	1764	441
V	3	1	BD	BD	BD	BD	BD	BD	1	1	BD	BD	BD	BD
Ti	24	6	721	180	70	17	BD	BD	BD	BD	BD	BD	BD	BD
Cu	250	63	11	3	16	4	BD	BD	BD	BD	BD	BD	13	3
Zn	10	3	115	29	709	177	BD	BD	2	1	BD	BD	45	11
Mn	12	3	180	45	105	26	BD	BD	130	33	BD	BD	1756	439
Ca	7	2	1	1	49	12	1	1	3	1	944	236	45	11
Mg	6	1	131	33	32	8	1	1	6	2	269	67	97	24
Na	5	1	44	11	3	1	1	1	1	1	224	56	107	27
K	3	1	355	89	13	3	1	1	1	1	198	50	149	37
Li	3	1	32	8	155	39	BD	BD	5	1	BD	BD	BD	BD
Sr	2	1	675	169	101	25	1	1	2	1	377	94	31	8
B	5	1	13	3	3	1	1	1	27	7	71	18	6	1
Ba	5	1	1224	306	41	10	BD	BD	158	39	236	59	53	13
P	7	2	180	45	1456	364	BD	BD	15	4	BD	BD	BD	BD
Mo	563	141	BD	BD	BD	BD	BD	BD	25	6	BD	BD	BD	BD
Ni	BD	BD	45	11	113	28	BD	BD	BD	BD	BD	BD	BD	BD
Se	BD	BD	BD	BD	1	1	BD	BD	BD	BD	BD	BD	BD	BD
As	20	5	128	32	30	7	BD	BD	124	31	BD	BD	11	3
S	5	1	38	10	9	2	1	1	1	1	251	63	8	2
Si	12	3	34	9	88	22	1	1	29	7	2	1	235	59

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * DAP – DAP (Cold Lake); IV1 – Invert (Rocky Mountain House); IV2 – Invert (Grande Prairie); KCl1 – KCl (Cold Lake); KCl2 – KCl (Waterton); NaCl1 – NaCl (Cold Lake); NaCl2 – NaCl (Slave Lake); Elements (Cd, Pb, and Co) below the detection limit are excluded from this table. BD = Below detection limit.

Table 16. Number of samples required to characterize the freshwater gel solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using the physical and chemical properties.

Variable	RM* 10%	RM 20%	RMW 10%	RMW 20%	GP1 10%	GP1 20%	GP2 10%	GP2 20%	GP3 10%	GP3 20%	CL 10%	CL 20%	WAT 10%	WAT 20%
pH ($CaCl_2$)	1	1	1	1	6	1	8	2	1	1	10	2	1	1
pH (H_2O)	1	1	1	1	9	2	13	3	1	1	12	3	1	1
ANC (%)	396	99	3	1	223	56	27	7	1142	285	439	110	52	13
$CaCO_3$ Eq (%)	325	81	12	3	291	73	77	19	1214	303	128	32	85	21
Ex Na (meq/100g)	23	6	792	198	372	93	62	15	78	19	43	11	1064	266
Ex K (meq/100g)	57	14	181	45	32	8	5	1	64	16	111	28	394	98
Ex Ca (meq/100g)	88	22	1616	404	93	23	175	44	136	34	728	182	73	18
Ex Mg (meq/100g)	7	2	113	28	111	28	180	45	41	10	694	174	450	112
CEC (meq/100g)	44	11	78	19	27	7	39	10	9	2	17	4	51	13
TIC (%)	327	82	11	3	291	73	78	19	1213	303	128	32	86	21
TOC (%)	986	247	40	10	56	14	77	19	98	24	61	15	413	103
TC (%)	792	198	13	3	96	24	51	13	35	9	30	7	331	83
Oil (%)	250	63	82	20	980	245	192	48	35	9	168	42	1059	265
Water (%)	94	23	184	46	192	48	602	150	14	3	76	19	134	33
Sand (%)	16	4	10	3	264	66	456	114	69	17	33	8	739	185
Silt (%)	49	12	11	3	14	3	40	10	1	1	10	2	149	37
Clay (%)	59	15	96	24	60	15	135	34	5	1	121	30	99	25

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * RM – Rocky Mountain House; RMW – Rocky Mountain House (Water – No Additives) Site; GP1 – Grande Prairie (Site 1); GP2 – Grande Prairie (Site 2); GP3 – Grande Prairie (Site 3); CL – Cold Lake Site; WAT – Waterton Site.

Table 17. Number of samples required to characterize the DAP, invert, KCl and NaCl solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using the physical and chemical properties.

Variable	DAP* 10%	DAP 20%	IV1 10%	IV1 20%	IV2 10%	IV2 20%	KCl1 10%	KCl 20%	KCl2 10%	KCl 20%	NaCl1 10%	NaCl1 20%	NaCl2 10%	NaCl2 20%
pH ($CaCl_2$)	14	4	1	1	1	1	8	2	1	1	7	2	2	1
pH (H_2O)	12	3	1	1	2	1	9	2	2	1	9	2	3	1
ANC (%)	360	90	33	8	38	10	82	21	28	7	45	11	133	33
$CaCO_3$ Eq (%)	215	54	43	11	18	4	19	5	58	14	46	12	215	54
Ex Na (meq/100g)	148	37	17	4	2	1	47	12	49	12	167	42	616	154
Ex K (meq/100g)	1	1	19	5	1	1	60	15	45	11	93	23	70	18
Ex Ca (meq/100g)	781	195	5	1	5	1	252	63	30	8	80	20	150	38
Ex Mg (meq/100g)	613	153	7	2	1	1	299	75	108	27	144	36	187	47
CEC (meq/100g)	71	18	8	2	3	1	22	5	115	29	12	3	131	33
TIC (%)	213	53	42	10	18	4	19	5	56	14	46	12	215	54
TOC (%)	187	47	12	3	6	2	44	11	302	76	76	19	160	40
TC (%)	79	20	11	3	6	2	32	8	228	57	48	12	148	37
Oil (%)	656	164	16	4	12	3	137	34	451	113	104	26	424	106
Water (%)	77	19	18	4	5	1	25	6	83	21	151	38	15	4
Sand (%)	54	13	11	3	20	5	4	1	55	14	10	2	71	18
Silt (%)	79	20	12	3	15	4	9	2	21	5	12	3	14	3
Clay (%)	214	54	23	6	29	7	17	4	26	7	48	12	238	59

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon. * DAP – DAP (Cold Lake); IV1 – Invert (Rocky Mountain House); IV2 – Invert (Grande Prairie); KCl1 – KCl (Cold Lake); KCl2 – KCl (Waterton); NaCl1 – NaCl (Cold Lake); NaCl2 – NaCl (Slave Lake).

with the lowest number of samples required to determine pH and the highest number required to determine extractable elements and oil content. Overall, the invert waste required the smallest number of samples suggesting that it is the least variable of the waste types sampled.

The large numbers of samples required for some of the waste parameters is mainly due to the presence of relatively small quantities of the various constituents. For example, the invert waste which contains considerably more oil than the other waste types required a small number of samples to assess oil content as compared to the other waste types.

4.3.2.2.2 Saturated paste extract properties. The number of samples required to characterize the solid phase wastes using saturated paste extract data is presented in Tables 18 and 19. The number of samples required varied widely between waste type for the various parameters. In general, the lowest number of samples is required to determine pH, saturation, % and EC. Again the large numbers of samples required appear to be associated with the trace elements whose concentrations were low and generally close to the detection limits of the instrument. The invert wastes required the lowest number of samples to complete the characterization for the parameters involved.

4.3.2.2.3 DTPA extract data. The number of samples required to characterize the solid phase wastes using DTPA extract data is presented in Tables 20 and 21. The number of samples needed for characterization varied from 1 to 1099 (accuracy of 10% of mean) and from 1 to 432 (accuracy of 20% of mean).

4.3.2.2.4 Total elemental analysis data. The number of samples required to characterize the solid phase wastes using total elemental analyses data is presented in Tables 22 and 23. The number of samples required for characterization ranged from 1 to 1396 (accuracy of 10% of mean) and 1 to 349 (accuracy of 20% of mean). Most of the

Table 18. Number of samples required to characterize the freshwater gel wastes (0.05 probability and accuracy of 10% or 20% of the mean) using the saturated paste extract data.

Variable	RM* 10%	RM 20%	RMW 10%	RMW 20%	GP1 10%	GP1 20%	GP2 10%	GP2 20%	GP3 10%	GP3 20%	CL 10%	CL 20%	WAT 10%	WAT 20%
Sat'n (%)	20	5	2	1	65	16	76	19	23	6	32	8	51	13
E.C. (dS/m)	5	1	19	5	299	75	73	18	29	7	40	10	130	33
pH	1	1	1	1	12	3	7	2	11	3	11	3	1	1
Alkalinity	37	9	17	4	61	15	310	78	112	28	1004	251	566	142
HCO3	29	7	17	4	107	27	350	87	114	29	355	89	369	92
CO3	226	57	315	79	1537	384	444	111	1689	422	3348	837	822	206
OH	136	34	250	63	8437	2109	632	158	1348	337	4067	1017	260	65
Cl	148	37	31	8	346	86	568	142	691	173	113	28	174	44
Ca	255	64	19	5	260	65	304	76	991	248	470	118	2203	551
Mg	304	76	95	24	785	196	1733	433	438	110	908	227	979	245
Na	8	2	74	18	563	141	184	46	30	8	50	12	209	52
K	76	19	116	29	197	49	154	39	3	1	458	115	127	32
Sr	128	32	133	33	392	98	152	38	707	177	205	51	750	187
S	26	7	25	6	523	131	63	16	419	105	142	35	305	76
Al	2434	608	7	2	126	31	149	37	210	52	228	57	1021	255
Cr	445	111	BD	BD	655	164	BD	BD	BD	BD	1238	310	1698	424
Fe	3296	824	BD	BD	582	146	63	16	1183	296	2355	589	927	232
V	111	28	BD	BD	101	25	BD	BD	BD	BD	1410	352	498	124
Ti	2940	735	63	16	130	32	302	76	4	1	549	137	630	158
Cu	1000	250	250	63	388	97	4	1	BD	BD	367	92	280	70
Pb	BD	BD	1	1	BD	BD	BD	BD	BD	BD	BD	BD	1750	438
Zn	218	54	46	11	290	73	520	130	30	7	50	13	169	42
Mn	2251	563	40	10	434	109	4748	1187	459	115	527	132	BD	BD
Li	63	16	168	42	104	26	1123	281	302	76	454	114	BD	BD
B	71	18	117	29	129	32	181	45	65	16	394	98	209	52
Ba	2390	597	63	16	613	153	844	211	854	213	1321	330	630	158
P	184	46	28	7	630	158	1336	334	1247	312	33	8	424	106
Mo	72	18	445	111	206	52	252	63	69	17	72	18	38	10
Ni	BD	BD	BD	BD	1	1	2406	601	BD	BD	BD	BD	BD	BD
Se	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	78	20	70	18
Co	BD	BD	BD	BD	BD	BD	1069	267	BD	BD	BD	BD	BD	BD
Si	579	579	24	24	600	150	195	49	410	102	231	58	84	84
As	20	20	BD	BD	339	85	413	103	53	13	BD	BD	85	85
SAR	4	4	32	32	386	96	239	60	233	58	96	24	78	78

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity; SAR = Sodium Adsorption Ratio; * RM – Rocky Mountain House; RMW – Rocky Mountain House (Water – No Additives) Site; GP1 – Grande Prairie (Site 1); GP2 – Grande Prairie (Site 2); GP3 – Grande Prairie (Site 3); CL – Cold Lake Site; WAT – Waterton Site; Elements (Cd) below the detection limit are excluded from this table. BD = Elements below detection limit.

Table 19. Number of samples required to characterize the DAP, invert, KCl and NaCl solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using the saturated paste extract data.

Variable	DAP* 10%	DAP 20%	IV1 10%	IV1 20%	IV2 10%	IV2 20%	KCl1 10%	KCl1 20%	KCl2 10%	KCl2 20%	NaCl1 20%	NaCl1 20%	NaCl2 10%	NaCl2 20%
Sat'n (%)	44	11	8	2	7	2	7	2	10	3	23	6	30	8
E.C. (dS/m)	161	40	5	1	4	1	43	11	63	16	33	8	472	118
pH	15	4	1	1	4	1	9	2	2	1	8	2	4	1
Alkalinity	337	84	18	4	19	5	37	9	66	17	963	241	1086	271
HCO3	739	185	16	4	28	7	119	30	62	16	1500	375	1068	267
CO3	742	185	457	114	611	153	2397	599	807	202	1704	426	3843	961
OH	1378	344	757	189	908	227	3521	880	521	130	3018	755	2152	538
Cl	350	88	9	2	7	2	67	17	128	32	66	16	803	201
Ca	1438	359	8	2	31	8	77	19	1114	279	41	10	320	80
Mg	1166	291	37	9	128	32	451	113	769	192	582	146	981	245
Na	503	126	22	6	6	1	39	10	92	23	62	15	742	186
K	739	185	7	2	6	1	74	18	147	37	60	15	409	102
Sr	1533	383	28	7	91	23	177	44	1032	258	98	24	1197	299
S	263	66	103	26	88	22	41	10	66	16	88	22	51	13
Al	479	120	4	1	5	1	81	20	450	113	32	8	163	41
Cr	6	1	BD	BD	BD	BD	5322	1330	158	39	4056	1014	1565	391
Fe	1052	263	84	21	1290	323	1285	321	158	39	3383	846	1493	373
V	479	120	47	12	1408	352	BD	BD	BD	BD	BD	BD	BD	BD
Ti	160	40	8	2	4	1	BD	BD	158	39	BD	BD	96	24
Cu	148	37	19	5	15	4	5434	1358	1418	354	1329	332	2418	604
Pb	BD	BD	139	35	23	6	BD	BD	1244	311	BD	BD	BD	BD
Zn	3	1	29	7	17	4	408	102	584	146	177	44	226	56
Mn	BD	BD	371	93	839	210	983	246	1613	403	3982	995	541	135
Li	290	73	28	7	86	21	358	89	1014	253	378	95	613	153
B	712	178	32	8	55	14	317	79	2257	564	814	203	108	27
Ba	2997	749	2789	697	444	111	45	11	630	158	224	56	163	41
P	2102	526	28	7	5	1	596	149	74	19	935	234	540	135
Mo	474	118	131	33	30	7	48	12	99	25	264	66	284	71
Ni	66	16	100	25	6	2	BD	BD	529	132	BD	BD	1028	257
Co	BD	BD	30	8	50	13	BD	BD	2520	630	BD	BD	BD	BD
Si	66	66	1	1	196	49	78	19	140	140	61	15	224	56
As	186	186	3	3	6	2	BD	BD	BD	BD	BD	BD	136	34
SAR	218	218	4	4	5	1	59	15	30	30	99	25	567	142

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity; SAR = Sodium Adsorption Ratio;
* DAP – DAP (Cold Lake); IV1 – Invert (Rocky Mountain House); IV2 – Invert (Grande Prairie); KCl1 – KCl (Cold Lake); KCl2 – KCl (Waterton); NaCl1 – NaCl (Cold Lake); NaCl2 – NaCl (Slave Lake); Elements (Cd and Se) below the detection limit are excluded from this table. BD = Elements below detection limit.

Table 20. Number of samples required to characterize the freshwater gel solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using DTPA extractable element data.

Variable	RM* 10%	RM 20%	RMW 10%	RMW 20%	GP1 10%	GP1 20%	GP2 10%	GP2 20%	GP3 10%	GP3 20%	CL 10%	CL 20%	WAT 10%	WAT 20%
Fe	11	3	130	33	103	26	144	36	73	18	183	46	22	5
Cd	BD	BD	BD	BD	50	12	127	32	45	11	84	21	BD	BD
Cu	51	13	38	10	31	8	181	45	58	15	16	4	108	27
Pb	149	37	280	70	172	43	618	155	39	10	282	70	20	5
Zn	41	10	36	9	79	20	226	57	99	25	131	33	157	39
Mn	17	4	80	20	154	39	88	22	30	7	138	35	44	11
Ca	1	1	8	2	57	14	40	10	19	5	140	35	17	4
Mg	14	3	88	22	205	51	133	33	69	17	242	60	190	47
Na	31	8	513	128	466	116	61	15	72	18	96	24	172	43
K	57	14	43	11	31	8	7	2	40	10	40	10	208	52
B	BD	BD	BD	BD	291	73	477	119	232	58	30	7	143	36
P	145	36	445	111	798	199	832	208	1728	432	122	30	266	67
Mo	119	30	BD	BD	256	64	224	56	31	8	27	7	60	15
Ni	20	5	149	37	68	17	241	60	1	1	111	28	55	14
Se	BD	BD	BD	BD	261	65	BD	BD	13	3	39	10	540	135

* RM – Rocky Mountain House; RMW – Rocky Mountain House (Water – No Additives) Site; GP1 – Grande Prairie (Site 1); GP2 – Grande Prairie (Site 2); GP3 – Grande Prairie (Site 3); CL – Cold Lake Site; WAT – Waterton Site; BD = Elements below detection limit.

Table 21. Number of samples required to characterize the DAP, invert, KCl and NaCl solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using the DTPA extractable element data.

Variable	DAP* 10%	DAP 20%	IV1 10%	IV1 20%	IV2 10%	IV2 20%	KCl1 10%	KCl1 20%	KCl2 10%	KCl2 20%	NaCl1 10%	NaCl1 20%	NaCl2 10%	NaCl2 20%
Fe	412	103	57	14	43	11	75	19	34	9	31	8	35	9
Cd	BD	BD	BD	BD	2	1	26	6	BD	BD	BD	BD	42	10
Cu	1099	275	113	28	63	16	8	2	19	5	59	15	58	15
Pb	374	93	67	17	72	18	116	29	1	1	62	15	81	20
Zn	362	90	322	80	73	18	51	13	52	13	96	24	43	11
Mn	311	78	159	40	39	10	108	27	66	16	149	37	186	46
Ca	153	38	3	1	6	1	74	19	26	7	108	27	102	25
Mg	205	51	9	2	22	5	92	23	236	59	103	26	246	62
Na	184	46	20	5	6	1	44	11	66	16	118	29	497	124
K	537	134	10	2	8	2	44	11	41	10	76	19	74	19
B	45	11	46	11	3	1	73	18	687	172	67	17	239	60
P	236	59	241	60	24	6	69	17	66	16	39	10	106	26
Mo	184	46	BD	BD	89	22	20	5	50	13	11	3	125	31
Ni	215	54	161	40	59	15	39	10	233	58	79	20	39	10
Se	19	5	BD	BD	BD	BD	BD	BD	21	5	BD	BD	813	203

* DAP – DAP (Cold Lake); IV1 – Invert (Rocky Mountain House); IV2 – Invert (Grande Prairie); KCl1 – KCl (Cold Lake); KCl2 – KCl (Waterton); NaCl1 – NaCl (Cold Lake); NaCl2 – NaCl (Slave Lake); BD = Elements below detection limits.

Table 22. Number of samples required to characterize the freshwater gel solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using total elemental analysis data.

Variable	RM* 10%	RM 20%	RMW 10%	RMW 20%	GP1 10%	GP1 20%	GP2 10%	GP2 20%	GP3 10%	GP3 20%	CL 10%	CL 20%	WAT 10%	WAT 20%
Mn	41	10	74	18	171	43	71	18	67	17	22	6	27	7
Na	262	65	201	50	134	34	48	12	23	6	19	5	58	14
K	62	15	77	19	12	3	11	3	7	2	14	3	30	8
Ca	22	6	140	35	32	8	42	11	97	24	473	118	92	23
Mg	98	25	26	7	31	8	22	6	67	17	10	3	85	21
Cu	BD	BD	BD	BD	32	8	31	8	6	1	38	10	17	4
Zn	55	14	13	3	15	4	38	9	33	8	13	3	48	12
P	79	20	30	7	34	9	145	36	12	3	18	4	14	3
Mo	BD	BD	BD	BD	15	4	4	1	9	2	BD	BD	72	18
Al	40	10	77	19	69	17	12	3	46	11	15	4	38	9
Fe	29	7	58	15	12	3	7	2	7	2	9	2	16	4
Ti	78	20	38	10	16	4	8	2	3	1	21	5	25	6
V	67	17	24	6	26	7	12	3	36	9	22	6	26	7
Cr	60	15	31	8	89	22	8	2	18	5	18	4	169	42
Ba	193	48	1396	349	36	9	32	8	770	192	29	7	119	30
Ni	130	33	33	8	30	8	20	5	38	9	43	11	488	122
Sr	57	14	573	143	33	8	10	3	12	3	4	1	39	10
Li	1	1	5	1	32	8	11	3	30	8	67	17	39	10
Zr	90	22	BD	BD	16	4	26	6	47	12	32	8	24	6

* RM – Rocky Mountain House; RMW – Rocky Mountain House (Water – No Additives) Site; GP1 – Grande Prairie (Site 1); GP2 – Grande Prairie (Site 2); GP3 – Grande Prairie (Site 3); CL – Cold Lake Site; WAT – Waterton Site; BD = Elements below detection limit.

Table 23. Number of samples required to characterize the DAP, invert, KCl and NaCl solid phase wastes (0.05 probability and accuracy of 10% or 20% of the mean) using total elemental analysis data.

Variable	DAP* 10%	DAP 20%	IV1 10%	IV1 20%	IV2 10%	IV2 20%	KCl1 10%	KCl1 20%	KCl2 10%	KCl2 20%	NaCl1 10%	NaCl1 20%	NaCl2 10%	NaCl2 20%
Mn	53	13	44	11	97	24	2	1	33	8	41	10	86	22
Na	30	8	19	5	47	12	5	1	38	9	177	44	368	92
K	47	12	10	2	5	1	11	3	41	10	32	8	57	14
Ca	113	28	25	6	53	13	104	26	162	40	87	22	288	72
Mg	87	22	8	2	67	17	1	1	25	6	35	9	224	56
Cu	617	154	24	6	19	5	12	3	39	10	98	25	173	43
Zn	70	17	69	17	3	1	25	6	23	6	67	17	49	12
P	179	45	9	2	6	2	7	2	32	8	29	7	162	40
Mo	1	1	21	5	22	5	BD	BD	1	1	BD	BD	20	5
Al	432	108	17	4	6	2	2	1	311	78	18	4	1279	320
Fe	60	15	10	2	5	1	2	1	63	16	23	6	61	15
Ti	102	26	10	2	2	1	1	1	54	14	39	10	134	33
V	143	36	20	5	7	2	8	2	80	20	39	10	299	75
Cr	71	18	15	4	6	1	64	16	48	12	51	13	978	244
Ba	179	45	57	14	168	42	2	1	217	54	13	3	920	230
Ni	67	17	41	10	23	6	6	2	36	9	46	11	80	20
Sr	73	18	13	3	9	2	20	5	929	232	29	7	334	83
Li	33	8	47	12	21	5	14	3	27	7	43	11	26	7
Zr	152	38	44	11	10	2	9	2	109	27	49	12	653	163

* DAP – DAP (Cold Lake); IV1 – Invert (Rocky Mountain House); IV2 – Invert (Grande Prairie); KCl1 – KCl (Cold Lake); KCl2 – KCl (Waterton); NaCl1 – NaCl (Cold Lake); NaCl2 – NaCl (Slave Lake);BD = Elements below detection limit.

elements could be characterized with less than 20 samples and in many cases with less than 10 samples at 20% accuracy. The DAP (Cold Lake) and NaCl (Slave Lake) wastes required the largest number of samples which is related to their high variability in characteristics. Both of these particular sumps had more than one major type of waste disposed of in the same sump cell which explains some of the variability.

5. RESULTS AND DISCUSSION - GREENHOUSE POT TRIALS

5.1 TRIAL TREATMENTS

The soil materials used for the greenhouse pot trials were obtained from locations adjacent to the respective waste sampling sites. The rates of waste material added were based on chloride content (Table 24) and liming potential. A detailed description of the treatments utilized is presented in Tables 25 to 27.

Because of the low chloride rate contained in some of the freshwater gel wastes and the DAP wastes these materials were added on a weight proportion basis or on a liming rate basis. For example, to increase the pH of the Cold Lake pot soil from its actual value of 6.35 to a pH of 7 necessitated 12.5 g, 15 g and 30 g waste/kg of soil for the freshwater gel, NaCl, and KCl wastes respectively. It is important to note that the 200 kg/ha rate of chloride which is equivalent to 114 g freshwater gel waste per 1 kg waste/soil mixture exceeded the rate required to bring the pot soil mixture to a pH of 7 by almost 10 fold. To achieve the 1200 kg Cl/ha rate of freshwater gel, 682 g of waste was added to 318 g of soil thereby resulting in a mixture of two parts waste to one part soil. In contrast only relatively small amounts of the KCl and NaCl wastes were required to achieve the chloride rates utilized (Table 25).

5.2 PLANT GROWTH

Three separate greenhouse experiments were conducted to coincide with the respective sampling and characterization activities. Germination was relatively good except for the pots with the higher applications of invert waste where crusting became a problem.

Height growth was enhanced to some extent by the addition of all wastes except the invert to the respective soil materials. Height of the grass may have increased with addition of waste, however, the number and size of leaves was likely affected. For most of the wastes the greatest mean height was achieved at the lowest

Table 24. Chloride content of the wastes and pot soils.

Waste Type	Location	Chloride Content (mg/kg)
Freshwater gel	Cold Lake	903
Freshwater gel	Rocky Mtn House	51
Freshwater gel	Waterton	938
Freshwater gel	Grande Prairie	187
DAP	Cold Lake	178
Invert	Rocky Mtn House	19100
Invert	Grande Prairie	20930
KCl	Cold Lake	14900
KCl	Waterton	51250
NaCl	Cold Lake	52700
NaCl	Red Earth Creek	43750
Water (no additives)	Rocky Mtn House	2315
Soil	Cold Lake	8
Soil	Cold Lake	23
Soil	Rocky Mtn House	11
Soil	Waterton	15
Soil	Grande Prairie	31
Soil	Red Earth Creek	45

Table 25. Drilling waste rate (g waste/kg soil) treatments based on chloride content and liming potential for the Cold Lake region.

Location	Waste	Reps.	Cl Rate kg/ha	Waste (g)	F. Cap* Waste (%)	Soil (g)	F. Cap Soil (%)	Waste & Soil (g)	Soil,Pot Waste,H2O (g)	Water (g)
Cold Lake	DAP	3	10	27	42.96	973	14.10	1000	1204	149
Cold Lake	DAP	3	124	333	42.96	667	14.10	1000	1292	237
Cold Lake	DAP	3	249	667	42.96	333	14.10	1000	1388	333
Cold Lake	DAP	3	373	1000	42.96	0	14.10	1000	1485	430
Cold Lake	Freshwater	3	20	12	40.98	988	12.75	1000	1186	131
Cold Lake	Freshwater	3	40	23	40.98	977	12.75	1000	1189	134
Cold Lake	Freshwater	3	80	45	40.98	955	12.75	1000	1195	140
Cold Lake	Freshwater	3	200	114	40.98	886	12.75	1000	1215	160
Cold Lake	Freshwater	3	400	227	40.98	773	12.75	1000	1247	192
Cold Lake	Freshwater	3	600	341	40.98	659	12.75	1000	1279	224
Cold Lake	Freshwater	3	800	455	40.98	545	12.75	1000	1311	256
Cold Lake	Freshwater	3	1200	682	40.98	318	12.75	1000	1375	320
Cold Lake	KCl	3	200	7	37.39	993	12.75	1000	1184	129
Cold Lake	KCl	3	400	14	37.39	986	12.75	1000	1186	131
Cold Lake	KCl	3	600	20	37.39	980	12.75	1000	1187	132
Cold Lake	KCl	3	800	27	37.39	973	12.75	1000	1189	134
Cold Lake	KCl	3	1200	41	37.39	959	12.75	1000	1193	138
Cold Lake	KCl	3	2400	83	37.39	917	12.75	1000	1203	148
Cold Lake	NaCl	3	1520	15	41.25	985	12.75	1000	1187	132
Cold Lake	NaCl	3	200	2	41.25	998	12.75	1000	1183	128
Cold Lake	NaCl	3	400	4	41.25	996	12.75	1000	1184	129
Cold Lake	NaCl	3	600	6	41.25	994	12.75	1000	1184	129
Cold Lake	NaCl	3	800	8	41.25	992	12.75	1000	1185	130
Cold Lake	NaCl	3	1200	12	41.25	988	12.75	1000	1186	131
Cold Lake	NaCl	3	2400	23	41.25	977	12.75	1000	1189	134
Cold Lake	Soil (DAP)	6	0	0	0.00	1000	12.75	1000	1183	128
Cold Lake	Soil	9	0	0	0.00	1000	14.10	1000	1196	141

* F. Cap = Field Capacity.

Table 26. Drilling waste rate (g waste/kg soil) treatments based on chloride content and liming potential for the Foothills region.

Location	Waste	Reps	Cl Rate kg/ha	Waste (g)	F. Cap* Waste (%)	Soil (g)	F. Cap Soil (%)	Waste & Soil (g)	Soil,Pot Waste,H2O (g)	Water (g)
Waterton	Freshwater	3	200.0	42.0	121.75	958.0	29.21	1000	1386	331
Waterton	Freshwater	3	400.0	84.0	121.75	916.0	29.21	1000	1425	370
Waterton	Freshwater	3	600.0	125.0	121.75	875.0	29.21	1000	1463	408
Waterton	Freshwater	3	800.0	167.0	121.75	833.0	29.21	1000	1502	447
Waterton	Freshwater	3	1200.0	251.0	121.75	749.0	29.21	1000	1579	524
Waterton	Freshwater	3	2400.0	502.0	121.75	498.0	29.21	1000	1812	757
Waterton	KCl	3	200.0	3.1	37.00	996.9	29.21	1000	1347	292
Waterton	KCl	3	400.0	6.3	37.00	993.7	29.21	1000	1348	293
Waterton	KCl	3	600.0	9.4	37.00	990.6	29.21	1000	1348	293
Waterton	KCl	3	800.0	12.6	37.00	987.4	29.21	1000	1348	293
Waterton	KCl	3	1200.0	18.8	37.00	981.2	29.21	1000	1349	294
Waterton	KCl	3	2400.0	38.0	37.00	962.0	29.21	1000	1350	295
Rocky Mtn.	Freshwater	3	17.0	333.0	20.12	667.0	26.40	1000	1298	243
Rocky Mtn.	Freshwater	3	25.0	667.0	20.12	333.0	26.40	1000	1277	222
Rocky Mtn.	Freshwater	3	51.0	1000.0	20.12	0.0	26.40	1000	1256	201
Rocky Mtn.	Freshwater	3	200.0	74.0	28.67	926.0	26.40	1000	1321	266
Rocky Mtn.	Freshwater	3	400.0	148.0	28.67	852.0	26.40	1000	1322	267
Rocky Mtn.	Freshwater	3	600.0	222.0	28.67	778.0	26.40	1000	1324	269
Rocky Mtn.	Freshwater	3	800.0	297.0	28.67	703.0	26.40	1000	1326	271
Rocky Mtn.	Freshwater	3	1200.0	445.0	28.67	555.0	26.40	1000	1329	274
Rocky Mtn.	Freshwater	3	2400.0	890.0	28.67	110.0	26.40	1000	1339	284
Rocky Mtn.	Invert	3	200.0	11.4	14.75	988.6	26.40	1000	1318	263
Rocky Mtn.	Invert	3	400.0	23.0	14.75	977.0	26.40	1000	1316	261
Rocky Mtn.	Invert	3	600.0	34.0	14.75	966.0	26.40	1000	1315	260
Rocky Mtn.	Invert	3	800.0	46.0	14.75	954.0	26.40	1000	1314	259
Rocky Mtn.	Invert	3	1200.0	69.0	14.75	931.0	26.40	1000	1311	256
Rocky Mtn.	Invert	3	2400.0	137.0	14.75	863.0	26.40	1000	1303	248
Rocky Mtn.	Soil	6	0.0	0.0	0.00	1000.0	26.40	1000	1319	264
Waterton	Soil	6	0.0	0.0	0.00	1000.0	29.21	1000	1347	292

* F. Cap = Field Capacity

Table 27. Drilling waste rate (g waste/kg soil) treatments based on chloride content and liming potential for the Grande Prairie region.

Location	Waste	Rep	Cl Rate kg/ha	Waste (g)	F. Cap* Waste (%)	Soil (g)	F. Cap Soil (%)	Waste & Soil (g)	Soil,Pot, Waste,H2O (g)	Water (g)
G. Prairie	Freshwater	3	65	106	41.10	894	26.48	1000	1335	280
G. Prairie	Freshwater	3	204	333	41.10	667	26.48	1000	1368	313
G. Prairie	Freshwater	3	408	667	41.10	333	26.48	1000	1417	362
G. Prairie	Freshwater	3	612	1000	41.10	0	26.48	1000	1466	411
G. Prairie	Invert	3	200	12	17.38	988	26.48	1000	1319	264
G. Prairie	Invert	3	400	24	17.38	976	26.48	1000	1318	263
G. Prairie	Invert	3	600	35	17.38	965	26.48	1000	1317	262
G. Prairie	Invert	3	800	47	17.38	953	26.48	1000	1316	261
G. Prairie	Invert	3	1200	71	17.38	929	26.48	1000	1313	258
G. Prairie	Invert	3	2400	142	17.38	858	26.48	1000	1307	252
G. Prairie	Washed Inv.	3	400	24	17.38	976	26.48	1023	1318	263
G. Prairie	Washed Inv.	3	1200	71	17.38	929	26.48	1000	1313	258
G. Prairie	Washed Inv.	3	2400	142	17.38	858	26.48	1000	1307	252
Slave Lake	NaCl	3	200	5	63.07	995	21.07	1000	1268	213
Slave Lake	NaCl	3	400	11	63.07	989	21.07	1000	1270	215
Slave Lake	NaCl	3	600	16	63.07	984	21.07	1000	1272	217
Slave Lake	NaCl	3	800	21	63.07	979	21.07	1000	1275	220
Slave Lake	NaCl	3	1200	31	63.07	969	21.07	1000	1279	224
Slave Lake	NaCl	3	2400	63	63.07	937	21.07	1000	1292	237
G. Prairie	Soil	6	0	0	0.00	1000	26.48	1000	1320	265
Slave Lake	Soil	6	0	0	0.00	1000	21.07	1000	1266	211

* F. Cap = Field Capacity.

waste application rate and height decreased as waste concentration added increased.

5.3 YIELD MEASUREMENTS

The fresh and dry weights of the brome grass were determined for each of the treatments in the three individual experiments. A comparison of the mean weights of the grass shoots is presented in Tables 28 to 32 and mean yields on a waste type basis are illustrated in Figures 25 to 28.

Comparisons regarding the freshwater gel waste/soil mixtures are somewhat difficult to make because of the variation in treatments (Cl rate) for the different regions. For the Cold Lake material all freshwater gel waste application rates resulted in yields (dry weight basis) exceeding the control except the highest rate of 1200 kg Cl/ha. This trend was not exhibited for the Waterton and Grande Prairie freshwater gel waste/soil mixtures. For the DAP waste/soil mixtures significantly lower yields were obtained at the two highest waste application rates. For the invert waste/soil mixtures there were significant reductions in yield from the control value as waste application rate increased.

The impact of KCl waste application differed for the Cold Lake materials and the Waterton materials. For the Cold Lake materials all treatment yields except for the 2400 kg Cl/ha treatment were greater than the control soil yield. For the KCl materials from the Waterton site yield decreased as waste concentration increased.

Similar trends were noted with the NaCl wastes. For the Cold Lake material all of the treatment yields exceeded the control yield. For the Slave Lake material yield at the lower application rates was equivalent to the control values and decreased with increasing application rate.

There are a number of possible explanations for the results described, particularly with respect to the yields obtained for the KCl and NaCl wastes from the Cold Lake area. Firstly, the controlled

Table 28. Comparison of the mean weights (g) of the brome grass grown in freshwater gel waste/soil mixtures.

Location	Cl Rate kg/ha	N	--- Grass (g) -- Fresh	Dry	Fresh/ Dry Ratio
Cold Lake	0	3	4.50ab*	1.10a	4.09
Cold Lake	20	3	5.25a	2.03a	2.59
Cold Lake	40	3	4.74ab	1.98a	2.39
Cold Lake	80	3	3.54b	1.64a	2.16
Cold Lake	200	3	5.57a	1.65a	3.38
Cold Lake	400	3	5.72a	1.47a	3.89
Cold Lake	600	3	5.25a	1.28a	4.10
Cold Lake	800	3	4.74ab	1.22a	3.89
Cold Lake	1200	3	3.54b	1.03a	3.44
Rocky Mtn.	0	3	6.54bc	1.82ab	3.59
Rocky Mtn.	17	3	8.90a	2.55a	3.49
Rocky Mtn.	25	3	7.06ab	2.01a	3.51
Rocky Mtn.	51	3	4.55c	1.03b	4.42
Waterton	0	3	7.34a	1.64a	4.48
Waterton	200	3	6.44a	1.24a	5.19
Waterton	400	3	7.18a	1.44a	4.99
Waterton	600	3	6.34ab	1.48a	4.28
Waterton	800	3	7.36a	1.64a	4.49
Waterton	1200	3	6.45a	1.36a	4.74
Waterton	2400	3	3.31b	0.49b	6.76
G. Prairie	0	3	8.74ab	2.34a	3.74
G. Prairie	65	3	9.90a	2.69a	3.68
G. Prairie	204	3	10.5a	2.60a	4.04
G. Prairie	408	3	6.75b	1.65b	4.09
G. Prairie	612	3	3.07c	0.73c	4.21

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 29. Comparison of the mean weights (g) of the brome grass grown in DAP waste/soil mixtures.

Location	Cl Rate kg/ha	N	-- Grass (g) -- Fresh	Dry	Fresh/ Dry Ratio
Cold Lake	0	3	6.91a*	1.60a	4.32
Cold Lake	10	3	7.03a	1.75a	4.02
Cold Lake	124	3	8.70a	1.75a	4.97
Cold Lake	249	3	2.06a	0.36b	5.72
Cold Lake	373	3	3.95b	0.63b	6.27

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 30. Comparison of the mean weights (g) of the brome grass grown in invert waste/soil mixtures.

Location	Cl Rate kg/ha	N	--- Grass (g) ---- Fresh	Dry	Fresh/ Dry Ratio
Rocky Mtn.	0	3	6.54a*	1.82a	3.59
Rocky Mtn.	200	3	4.56b	1.09bc	4.18
Rocky Mtn.	400	3	4.46b	1.17b	3.81
Rocky Mtn.	600	3	3.42bc	0.66cde	5.18
Rocky Mtn.	800	3	3.98b	0.87bcd	4.57
Rocky Mtn.	1200	3	2.79c	0.60de	4.65
Rocky Mtn.	2400	3	1.45d	0.22e	6.59
G. Prairie	0	3	8.74a	2.34a	3.74
G. Prairie	200	3	5.94b	1.27b	4.68
G. Prairie	400	3	4.46b	0.99b	4.51
G. Prairie	600	3	2.00cd	0.41c	4.88
G. Prairie	800	3	2.17c	0.43c	5.05
G. Prairie	1200	3	0.99cd	0.21c	4.71
G. Prairie	2400	3	0.10d	0.02c	5.00

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 31. Comparison of the mean weights (g) of the brome grass grown in KCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	--- Grass (g) -- Fresh	Dry	Fresh/ Dry Ratio
Cold Lake	0	3	4.50a*	1.10ab	4.09
Cold Lake	200	3	5.15a	1.71a	3.01
Cold Lake	400	3	4.94a	1.52ab	1.63
Cold Lake	600	3	5.41a	1.55ab	3.49
Cold Lake	800	3	4.85a	1.34ab	3.62
Cold Lake	1200	3	4.81a	1.37ab	3.51
Cold Lake	2400	3	4.11a	0.97b	4.24
Waterton	0	3	7.34a	1.64a	4.48
Waterton	200	3	6.59ab	1.51a	4.36
Waterton	400	3	6.79ab	1.43a	4.75
Waterton	600	3	6.70ab	1.46a	4.59
Waterton	800	3	5.17ab	1.02a	5.07
Waterton	1200	3	5.06ab	1.03a	4.91
Waterton	2400	3	4.82b	0.97a	4.97

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 32. Comparison of the mean weights (g) of the brome grass grown in NaCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	--- Grass (g) -- Fresh	Dry	Fresh/ Dry Ratio
Cold Lake	0	3	4.50a*	1.10b	4.09
Cold Lake	200	3	5.32ab	1.92a	2.77
Cold Lake	400	3	5.37ab	1.75a	3.07
Cold Lake	600	3	5.45a	1.82a	2.99
Cold Lake	800	3	5.65a	1.92a	2.94
Cold Lake	1200	3	5.31ab	1.70a	1.56
Cold Lake	1520	3	5.10ab	1.65ab	3.09
Cold Lake	2400	3	5.75a	1.62ab	3.55
Slave Lake	0	3	7.38ab	1.89ab	3.91
Slave Lake	200	3	7.85a	1.92ab	4.09
Slave Lake	400	3	8.07a	1.97a	4.10
Slave Lake	600	3	6.63ab	1.53ab	4.33
Slave Lake	800	3	5.79ab	1.28ab	4.52
Slave Lake	1200	3	5.35b	1.17b	4.57
Slave Lake	2400	3	1.30c	0.27c	4.81

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

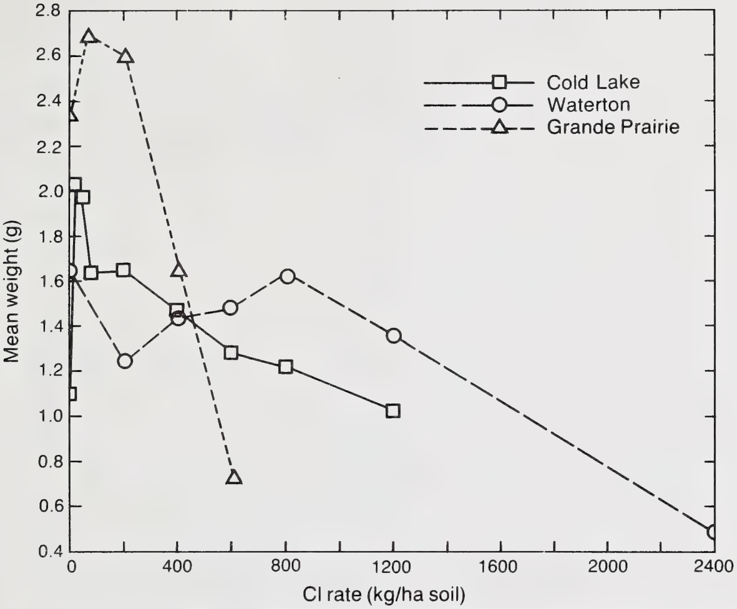


Figure 25. Mean yield (dry weight, g) of the brome grass grown in the freshwater gel waste/soil mixtures.

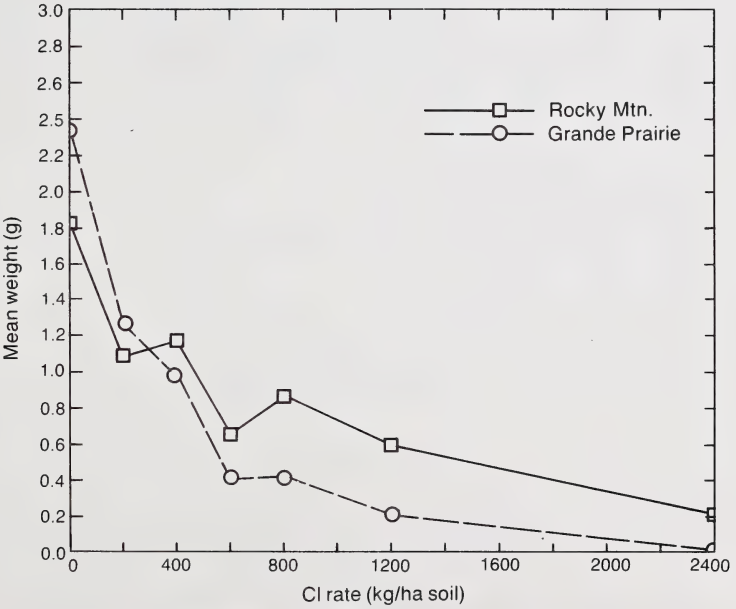


Figure 26. Mean yield (dry weight, g) of the brome grass grown in the invert waste/soil mixtures.

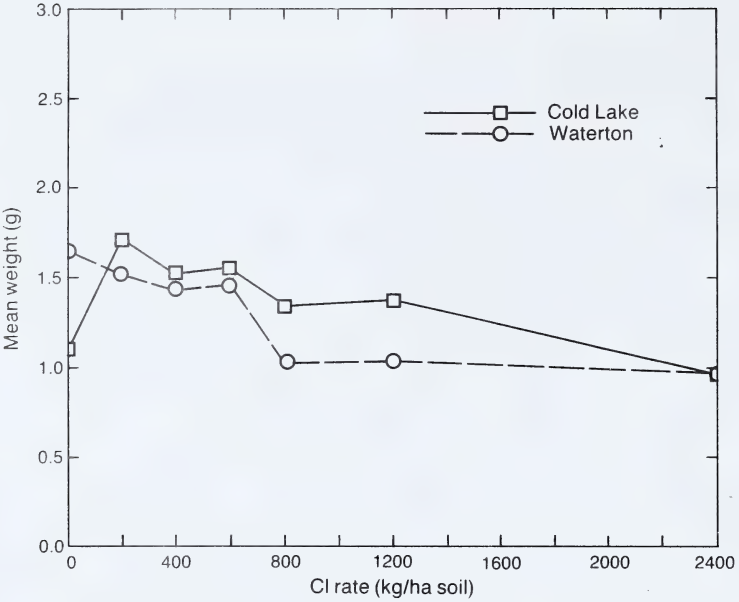


Figure 27. Mean yield (dry weight, g) of the brome grass grown in the KCl waste/soil mixtures.

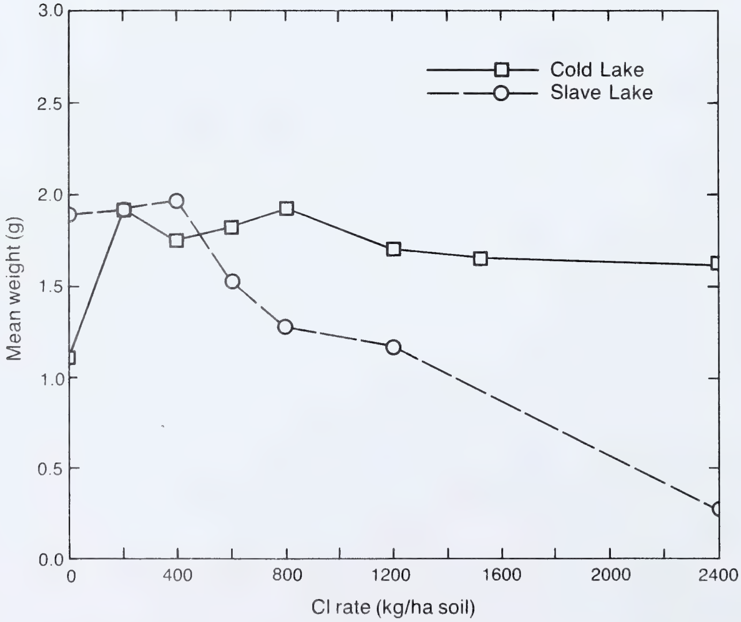


Figure 28. Mean yield (dry weight, g) of the brome grass grown in the NaCl waste/soil mixtures.

environment of the greenhouse could be masking impacts by not creating any stresses. For example, moisture levels were maintained at or very near field capacity. Secondly, it is possible that the waste improved the physical condition of the soil and likely added some nutrients.

5.4 POT TRIAL SOIL AND WASTE CHARACTERISTICS

The data for the chemical and physical properties, saturated paste extracts, total elemental analysis and DTPA extracts pertinent to the wastes and soil materials utilized in the greenhouse pot experiments are presented in Appendix 10.11. The bulk waste samples were comprised of material from all digs and all depths from each of the waste sample site locations.

5.5 CHEMICAL PROPERTIES OF THE WASTE/SOIL MIXTURES

The waste/soil mixtures contained in each of the pots were analysed following removal of the plant root and shoot material. A comparison of mean data for the physical and chemical properties is presented in Tables 33 to 37. Mean values for pH in the waste/soil mixtures are illustrated by waste type in Figures 29 to 32.

Significant increases in pH and $CaCO_3$ equivalent resulted from the addition of all freshwater gel wastes to soil. Significant increases in carbon resulted from the addition of freshwater gel wastes from the Cold Lake and Rocky Mountain House site. Similarly, the addition of DAP waste to soil resulted in significant increases in pH, $CaCO_3$ equivalent and carbon. The addition of invert wastes to soil resulted in significant increases in pH and total and organic carbon.

For the KCl waste/soil mixtures significant increases in $CaCO_3$ equivalent, pH ($CaCl_2$) and inorganic carbon were evident. For the NaCl waste/soil mixtures significant increases in pH and $CaCO_3$ equivalent resulted from waste addition.

Table 33. Comparison of the chemical properties (mean values) of the freshwater gel waste/soil mixtures.

Location	Cl Rate kg/ha	N	pH H_2O	pH $CaCl_2$	$CaCO_3$ Eq	TC (%)	TIC (%)	TOC (%)
Cold Lake	0	3	5.73e*	5.40g	0.32f	0.59d	0.04f	0.55e
Cold Lake	20	3	7.03d	6.93f	0.05f	0.65d	0.01f	0.64e
Cold Lake	40	3	7.50c	7.20e	0.09f	0.62d	0.01f	0.61e
Cold Lake	80	3	7.57c	7.47d	0.43f	0.67d	0.05f	0.62e
Cold Lake	200	3	7.83bc	7.80c	1.00e	0.84d	0.12e	0.72de
Cold Lake	400	3	8.03ab	7.97bc	1.80d	1.19c	0.22d	0.97cd
Cold Lake	600	3	8.17ab	8.17ab	2.91c	1.49b	0.35c	1.14bc
Cold Lake	800	3	8.20a	8.27a	3.93b	1.74b	0.47b	1.27b
Cold Lake	1200	3	8.33a	8.40a	5.68a	2.50a	0.68a	1.82a
Rocky Mtn.	0	3	4.18d	0.11d	4.93d	1.57c	0.01d	1.55b
Rocky Mtn.	17	3	6.82c	1.29c	7.14c	2.29c	0.16c	2.13b
Rocky Mtn.	25	3	7.57b	2.92b	7.72b	3.50b	0.35b	3.15a
Rocky Mtn.	51	3	8.25a	4.65a	8.46a	4.69a	0.56a	4.13a
Waterton	0	3	5.98f	0.13e	6.26f	5.29a	0.02e	5.27a
Waterton	200	3	6.81e	0.29de	7.06e	4.94a	0.04de	4.91a
Waterton	400	3	7.19d	0.37cde	7.41d	5.20a	0.05cde	5.16a
Waterton	600	3	7.40d	0.58cd	7.58c	5.39a	0.07cd	5.32a
Waterton	800	3	7.64c	0.72c	7.66c	5.52a	0.09c	5.44a
Waterton	1200	3	7.89b	1.51b	7.84b	5.63a	0.18b	5.45a
Waterton	2400	3	8.48a	3.06a	8.44a	5.50a	0.37a	5.13a
G. Prairie	0	3	4.80e	0.01e	5.27e	2.48a	0.99a	1.49a
G. Prairie	65	3	6.90d	0.37d	7.07d	2.43a	0.97a	1.45a
G. Prairie	204	3	7.60c	1.87c	7.73c	2.30a	0.92a	1.38a
G. Prairie	409	3	8.10b	4.03b	8.17b	2.22a	0.89a	1.33a
G. Prairie	612	3	8.67a	6.35a	8.67a	2.12a	0.85a	1.27a

$CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon;
* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 34. Comparison of the chemical properties (mean values) of the DAP waste/soil mixtures.

Location	N	Cl Rate	pH		$CaCO_3$	TC	TIC	TOC
		kg/ha	H_2O	$CaCl_2$	Eq		(%)	
Cold Lake	3	0	5.94c*	5.54e	0.11d	0.59d	0.01d	0.58d
Cold Lake	3	10	6.76b	6.41d	0.08d	0.72d	0.01d	0.71d
Cold Lake	3	124	7.68a	7.49c	1.07c	1.13c	0.13c	1.00c
Cold Lake	3	249	7.71a	7.64b	2.42b	1.62b	0.29b	1.33b
Cold Lake	3	373	7.90a	7.88a	3.58a	2.13a	0.43a	1.70a

$CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 35. Comparison of the chemical properties (mean values) of the invert waste/soil mixtures.

Location	Rep	Cl Rate	pH		$CaCO_3$	TC	TIC	TOC
		kg/ha	H_2O	$CaCl_2$	Eq		(%)	
Rocky Mtn.	3	0	4.93b*	4.18f	0.11b	1.57bc	0.01b	1.55bc
Rocky Mtn.	3	200	4.77cd	4.26ef	0.10b	1.51c	0.01b	1.50c
Rocky Mtn.	3	400	4.67d	4.30e	0.07b	1.71bc	0.01b	1.70bc
Rocky Mtn.	3	600	4.64d	4.39d	0.09b	1.77bc	0.01b	1.76bc
Rocky Mtn.	3	800	4.70cd	4.48c	0.12b	1.90bc	0.01b	1.89abc
Rocky Mtn.	3	1200	4.84bc	4.72b	0.11b	2.00ab	0.01b	1.98ab
Rocky Mtn.	3	2400	5.54a	5.53a	0.27a	2.37a	0.03a	2.33a
G. Prairie	3	0	5.27e	4.80g	0.01b	2.48c	0.99c	1.49c
G. Prairie	3	200	5.30de	5.00f	0.06b	2.47c	0.99c	1.48c
G. Prairie	3	400	5.40de	5.20e	0.04b	2.61bc	1.05bc	1.57bc
G. Prairie	3	600	5.47cd	5.37d	0.05b	2.62bc	1.05bc	1.57bc
G. Prairie	3	800	5.60c	5.50c	0.04b	2.71bc	1.08bc	1.62bc
G. Prairie	3	1200	5.90b	5.93b	0.04b	3.01b	1.21b	1.81b
G. Prairie	3	2400	6.63a	6.63a	0.21a	3.57a	1.43a	2.14a

$CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 36. Comparison of the chemical properties (mean values) of the KCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	pH H2O	pH CaCl2	CaCO3 Eq	TC (%)	TIC (%)	TOC (%)
Cold Lake	0	3	5.73a*	5.40f	0.32ab	0.59b	0.04ab	0.55b
Cold Lake	200	3	6.50a	6.40e	0.00b	0.66b	0.00b	0.66b
Cold Lake	400	3	7.00a	6.57de	0.15ab	0.66b	0.02ab	0.64b
Cold Lake	600	3	5.97a	6.87cd	0.15ab	0.65b	0.02ab	0.64b
Cold Lake	800	3	7.20a	7.13bc	0.29ab	0.73b	0.04ab	0.69b
Cold Lake	1200	3	7.40a	7.37b	0.35ab	0.75b	0.04ab	0.71b
Cold Lake	2400	3	7.57a	7.77a	0.52a	1.04a	0.06a	0.98a
Waterton	0	3	6.26b	5.98e	0.13b	5.29a	0.02b	5.27a
Waterton	200	3	6.30b	6.15d	0.14b	5.19a	0.02b	5.17a
Waterton	400	3	6.30b	6.15d	0.16b	5.36a	0.02b	5.34a
Waterton	600	3	6.30b	6.21cd	0.12b	5.47a	0.01b	5.46a
Waterton	800	3	6.30b	6.29bc	0.20ab	5.63a	0.03ab	5.60a
Waterton	1200	3	6.30b	6.32b	0.21ab	5.31a	0.03ab	5.28a
Waterton	2400	3	6.50a	6.55a	0.29a	5.52a	0.04a	5.48a

CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon.
* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 37. Comparison of the chemical properties (mean values) of the NaCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	pH H2O	pH CaCl2	CaCO3 Eq	TC (%)	TIC (%)	TOC (%)
Cold Lake	0	3	5.73d*	5.40g	0.32a	0.59a	0.04a	0.55a
Cold Lake	200	3	6.13cd	5.93f	0.06ab	0.65a	0.01b	0.64a
Cold Lake	400	3	6.23cd	6.00de	0.01b	0.68a	0.01b	0.68a
Cold Lake	600	3	6.43bcd	6.33de	0.06ab	0.66a	0.01b	0.65a
Cold Lake	800	3	6.93abc	6.63cd	0.09ab	0.62a	0.01b	0.61a
Cold Lake	1200	3	7.03abc	6.90bc	0.13ab	0.66a	0.02ab	0.65a
Cold Lake	1520	3	7.27ab	7.23ab	0.15ab	0.70a	0.02ab	0.68a
Cold Lake	2400	3	7.47a	7.33a	0.31a	0.77a	0.04a	0.73a
Slave Lake	0	3	5.27f	4.80g	0.01d	1.72a	0.69a	0.87a
Slave Lake	200	3	5.70e	5.53f	0.04cd	1.71a	0.69a	1.03a
Slave Lake	400	3	6.30d	6.20e	0.10cd	1.59a	0.64a	0.95a
Slave Lake	600	3	6.60c	6.53d	0.20bcd	1.80a	0.72a	1.08a
Slave Lake	800	3	6.73c	6.70c	0.24bc	1.87a	0.75a	1.12a
Slave Lake	1200	3	6.97b	6.90b	0.34b	1.68a	0.67a	1.01a
Slave Lake	2400	3	7.20a	7.20a	0.84a	1.78a	0.71a	1.07a

CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon.

* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

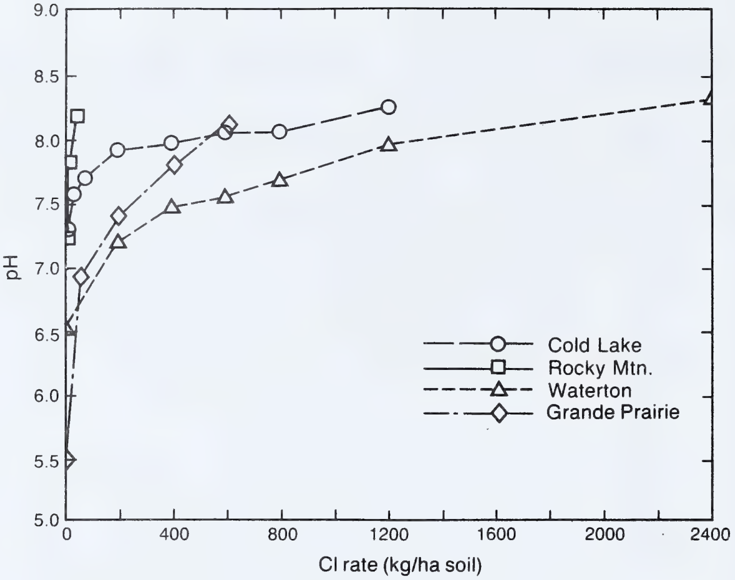


Figure 29. Mean pH values for the freshwater gel waste/soil mixtures.

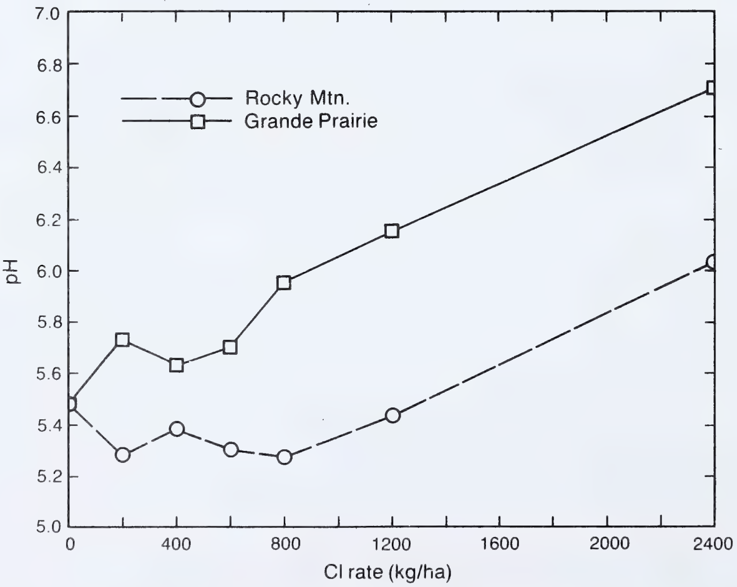


Figure 30. Mean pH values for the invert waste/soil mixtures.

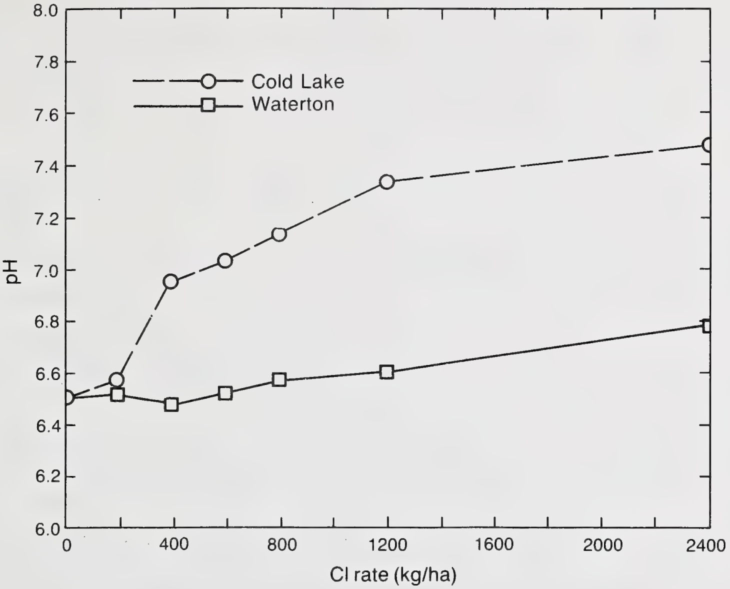


Figure 31. Mean pH values for the KCl waste/soil mixtures.

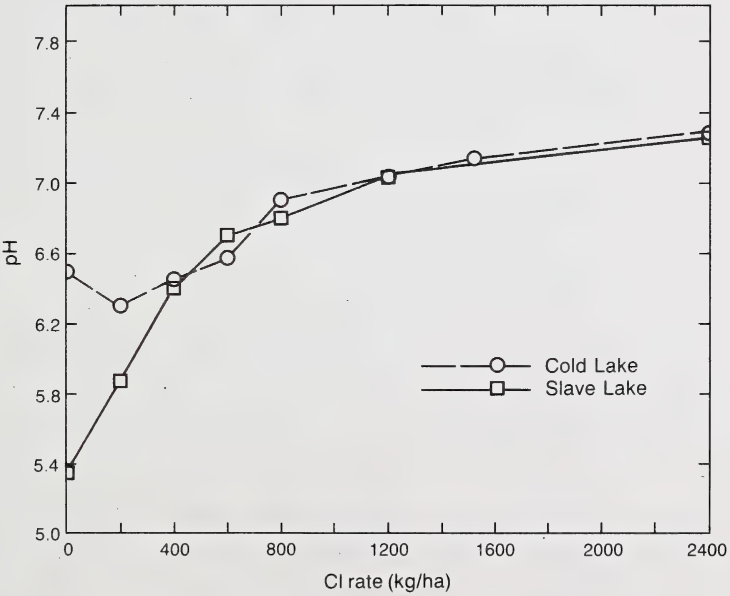


Figure 32. Mean pH values for the NaCl waste/soil mixtures.

5.6 SATURATED PASTE EXTRACT DATA FOR THE WASTE/SOIL MIXTURES

A comparison of the saturated paste extract mean data for the waste/soil mixtures is presented in Tables 38 to 42. Mean values for EC and SAR in the waste/soil mixtures are illustrated by waste type in Figures 33 to 40.

The data for the freshwater gel waste/soil mixtures indicated that Cd, Co, Li, Ni, Pb, Se, and V levels in the waste/soil mixtures were not significantly altered by the addition of waste to soil. The levels of Al, Ba, Ca, Cd, Co, Cr, Fe, Mg, Mn, Pb, Se, Sr, Ti, and Zn were not significantly altered by the addition of DAP waste to soil. Results for the invert waste/soil mixtures indicated that Cd, Cr, Li, Mo, Ni, Pb, Se, and V levels were not significantly altered by the addition of invert waste to soil. The levels of Cd, Co, Cr, Li, Mo, Ni, Pb, and Se were not significantly altered by the addition of KCl waste to soil. The data for the NaCl waste/soil mixtures indicated that the levels of Cd, Co, Cr, Li, Mo, Ni, Pb, Se, and V were not significantly altered by the addition of NaCl waste to soil. In summary, the levels of cadmium, lead and selenium were not significantly altered by the addition of all waste types to soil. Nickel, Co and Cr levels were not significantly altered by the addition of four of the waste types to soil.

The data indicated that significant increases in EC, SAR, and Cl content in the waste/soil mixtures occurred with increasing concentrations of all of the wastes from all sites. The EC levels could be limiting to plant growth at some of the higher rates utilized for all wastes. Miller and Peseran (1980) suggest that many plants exhibit severe reductions in growth when the soil-paste extract conductivity reaches about 8 to 15 dS/m. The Alberta Soils Advisory Committee (1977, 1987) suggests that moderate limitations to plant growth occur at EC levels of 4 to 8 dS/m and that severe limitations occur at levels greater than 8 dS/m. Interpretations relative to the impact of waste application on the suitability of the waste/soil mixtures for plant growth as measured by EC are presented in Table 43.

Table 38. Comparison of the saturated paste extract data (mean values) for the freshwater gel waste/soil mixtures.

Location	N	Cl Rate kg/ha	Sat'n (%)	E.C. (dS/m)	SAR	pH	Cl	Alk	HCO_3	CO_3	OH	NO_3	Al	Cr	Fe
							(mg/L)								
Cold Lake	3	0	34.3f*	0.16h	1.02h	6.50c	7.95e	78.7d	78.7d	0.05e	0.00d	0.09a	3.05a	0.02a	19.3a
Cold Lake	3	20	33.7f	0.77g	1.69gh	7.30b	9.05e	272b	272b	0.54de	0.01d	0.07a	0.50b	0.02a	0.09b
Cold Lake	3	40	33.0f	1.06fg	2.58fg	7.57ab	13.3e	285ab	284ab	0.99de	0.02cd	0.09a	0.61b	0.02a	0.06b
Cold Lake	3	80	37.8de	1.53f	3.68f	7.70ab	28.6de	277b	276b	1.36cd	0.03cd	0.10a	0.85b	0.02a	0.08b
Cold Lake	3	200	39.0d	2.91e	7.08e	7.92ab	102d	274b	272b	2.11bc	0.04bc	0.12a	1.32ab	0.02a	0.07b
Cold Lake	3	400	44.0c	4.65d	10.8d	7.97ab	260c	315a	312a	2.73ab	0.05bc	0.10a	1.90ab	0.02a	0.05b
Cold Lake	3	600	47.8c	6.00c	14.7c	8.05a	451b	290ab	287a	3.01ab	0.06b	0.11a	2.06ab	0.02a	0.04b
Cold Lake	3	800	52.1b	6.92b	18.1b	8.05a	520b	286ab	283ab	3.02ab	0.06b	0.11a	2.09ab	0.02a	0.03b
Cold Lake	3	1200	60.8a	8.08a	22.7a	8.24a	645a	210c	207c	3.41a	0.09a	0.11a	2.10ab	0.02a	0.01b
Rocky Mtn.	3	0	43.2ab	0.11d	0.87d	5.48d	8.15b	18.9c	18.9c	0.00b	0.00b	0.63a	8.13a	0.02a	8.21a
Rocky Mtn.	3	17	40.2b	1.78c	8.34c	7.23c	9.90b	319b	318b	0.51b	0.01b	0.02a	0.90b	0.02a	0.19b
Rocky Mtn.	3	25	41.2b	3.23b	20.2b	7.83b	14.1b	447a	444a	2.84a	0.03b	0.24a	0.78b	0.02a	0.10b
Rocky Mtn.	3	51	46.7a	4.38a	45.2a	8.19a	41.6a	273b	269b	4.01a	0.08a	0.25a	0.60b	0.02a	0.03b
Waterton	3	0	68.8c	0.69e	0.36g	6.50e	7.43f	87.7d	87.7d	0.03e	0.00e	5.33ab	0.69a	0.02d	0.07c
Waterton	3	200	70.2c	2.01d	6.12f	7.20d	111e	169cd	168cd	0.25de	0.01de	20.6a	0.98a	0.02d	0.15c
Waterton	3	400	71.2c	3.14c	11.9e	7.47c	215d	246bc	246bc	0.68cde	0.01cd	3.70ab	1.08a	0.02d	0.18c
Waterton	3	600	79.8c	4.00bc	16.7d	7.55c	271c	296ab	295ab	0.98cd	0.02cd	0.14b	1.11a	0.03d	0.20c
Waterton	3	800	84.2c	4.88ab	22.1c	7.68c	353b	318ab	316ab	1.44c	0.02c	0.04b	1.10a	0.04c	0.23bc
Waterton	3	1200	125b	4.79ab	30.6b	7.95b	379b	372a	369a	3.11b	0.04b	0.05b	0.84a	0.09b	0.45b
Waterton	3	2400	199a	5.66a	56.7a	8.30a	483a	350a	344a	6.45a	0.10a	0.15b	0.77a	0.26a	1.06a
G. Prairie	3	0	43.3e	0.25e	0.65e	5.48d	8.84d	58.6d	58.6d	1.70c	0.15b	0.08a	1.71d	0.02b	5.02a
G. Prairie	3	65	49.2d	3.40d	6.61d	6.93c	21.5d	223c	318b	259bc	4.37b	0.08a	2.06c	0.02b	0.12b
G. Prairie	3	204	58.7c	6.77c	18.2c	7.40b	109c	318b	488a	1150abc	12.6ab	0.08a	2.60a	0.02b	0.25b
G. Prairie	3	408	76.0b	9.59b	32.9b	7.80ab	208b	489a	432a	2560ab	31.6ab	0.11a	2.47ab	0.03a	0.24b
G. Prairie	3	612	94.3a	11.3a	43.6a	8.12a	253a	434a	220c	2940a	71.9a	0.23a	2.37b	0.02b	0.05b

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg $CaCO_3$/ L); SAR = Sodium Adsorption Ratio;
* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

continued...

Table 38. Continued.

Location	N	Cl Rate kg/ha	V	Ti	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li
									(mg/L)					
Cold Lake	3	0	0.05a*	0.99a	0.01a	0.04a	0.10a	0.18bcd	0.30b	18.9e	5.29f	19.5g	5.87f	0.04a
Cold Lake	3	20	0.03a	0.01b	0.01a	0.01b	0.10a	0.13cd	0.38a	128d	22.2e	78.3fg	4.69f	0.04a
Cold Lake	3	40	0.03a	0.01b	0.01a	0.01b	0.10a	0.12d	0.30b	150cd	25.0de	130fg	4.72f	0.04a
Cold Lake	3	80	0.03a	0.01b	0.01a	0.01b	0.10a	0.12d	0.19b	201c	32.1cd	214f	6.30ef	0.04a
Cold Lake	3	200	0.03a	0.01b	0.01a	0.01b	0.10a	0.16bcd	0.05c	320b	43.7b	511e	10.1e	0.04a
Cold Lake	3	400	0.03a	0.01b	0.01a	0.02ab	0.10a	0.19bcd	0.05c	460a	53.6a	922d	17.9d	0.04a
Cold Lake	3	600	0.03a	0.01b	0.01a	0.02ab	0.10a	0.21abc	0.04c	500a	55.4a	1300c	27.5c	0.04a
Cold Lake	3	800	0.03a	0.01b	0.01a	0.02ab	0.10a	0.22ab	0.04c	502a	50.1ab	1590b	35.6b	0.04a
Cold Lake	3	1200	0.03a	0.01b	0.01a	0.02b	0.10a	0.28a	0.02c	488a	34.3c	1930a	49.6a	0.04a
Rocky Mtn.	3	0	0.03a	0.50a	0.01a	0.04b	0.10a	0.14a	0.28a	9.10b	2.96c	11.8d	1.99c	0.04d
Rocky Mtn.	3	17	0.03a	0.02b	0.01a	0.07b	0.10a	0.10a	0.31a	136a	14.5a	382c	1.74c	0.08c
Rocky Mtn.	3	25	0.03a	0.01b	0.01a	0.10a	0.10a	0.14a	0.13a	116a	10.6ab	847b	5.37b	0.13b
Rocky Mtn.	3	51	0.03a	0.01b	0.01a	0.06a	0.10a	0.14a	0.02b	34.7b	8.55b	1140a	10.9a	0.22a
Waterton	3	0	0.03a	0.01a	0.01a	0.03bc	0.10a	0.07d	0.02c	134ab	23.2ab	16.94e	4.00f	0.04a
Waterton	3	200	0.03a	0.02a	0.01a	0.02c	0.10a	0.10cd	0.04bc	180ab	27.1a	332d	5.61ef	0.04a
Waterton	3	400	0.03a	0.01a	0.01a	0.03bc	0.10a	0.12cd	0.06abc	194a	24.5a	662c	7.04de	0.04a
Waterton	3	600	0.03a	0.01a	0.01a	0.02bc	0.10a	0.12cd	0.09abc	195a	22.7ab	924c	8.52cd	0.04a
Waterton	3	800	0.03a	0.01a	0.01a	0.03bc	0.10a	0.15bc	0.10abc	192a	22.1ab	1210b	10.5c	0.04a
Waterton	3	1200	0.03a	0.01a	0.01a	0.05ab	0.10a	0.18b	0.14a	105bc	12.5bc	1240ab	12.7b	0.04a
Waterton	3	2400	0.03a	0.01a	0.01a	0.07a	0.10a	0.24a	0.12ab	44.3c	5.85c	1510a	20.4a	0.04a
G. Prairie	3	0	0.03a	0.23a	0.01a	0.04bc	0.10a	0.16d	0.45b	37.4e	7.38d	16.7e	4.64e	0.04a
G. Prairie	3	65	0.03a	0.02b	0.01a	0.03c	0.10a	0.11e	0.99a	464c	61.0a	570d	8.61d	0.04a
G. Prairie	3	204	0.03a	0.03b	0.01a	0.05ab	0.10a	0.21c	0.55b	583a	56.9a	1720c	12.8c	0.04a
G. Prairie	3	408	0.03a	0.03b	0.01a	0.07a	0.10a	0.34b	0.33bc	498b	50.3b	2880b	20.3b	0.04a
G. Prairie	3	612	0.03a	0.02b	0.01a	0.04bc	0.10a	0.39a	0.09c	430d	14.0c	3380a	26.7a	0.04a

* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

continued...

Table 38. Concluded.

Location	N	Cl Rate kg/ha	Sr	B	Ba	P	Mo	Ni	Se	Co	S	Si	As
			(mg/L)										
Cold Lake	3	0	0.08e*	0.06d	0.10a	0.57a	0.05e	0.03a	0.30a	0.01a	3.75h	19.1a	0.06d
Cold Lake	3	20	0.24d	0.06d	0.09a	0.22d	0.05e	0.03a	0.30a	0.01a	67.8gh	5.08c	0.17ab
Cold Lake	3	40	0.29d	0.07d	0.08a	0.23d	0.05e	0.03a	0.30a	0.01a	132fg	5.97c	0.18a
Cold Lake	3	80	0.35d	0.13cd	0.12a	0.26cd	0.05e	0.03a	0.30a	0.01a	239f	8.11c	0.14c
Cold Lake	3	200	0.58c	0.24c	0.12a	0.35b	0.18e	0.03a	0.30a	0.01a	537e	10.7bc	0.15bc
Cold Lake	3	400	0.85b	0.45b	0.13a	0.34bc	0.37d	0.03a	0.30a	0.01a	885d	14.9ab	0.17ab
Cold Lake	3	600	1.02a	0.56ab	0.10a	0.25d	0.58c	0.03a	0.30a	0.01a	1130c	17.5a	0.15bc
Cold Lake	3	800	1.12a	0.62a	0.09a	0.23d	0.80b	0.03a	0.30a	0.01a	1310b	19.1a	0.14c
Cold Lake	3	1200	1.16a	0.68a	0.35a	0.13e	1.13a	0.03a	0.30a	0.01a	1520a	20.3a	0.09d
Rocky Mtn.	3	0	0.04b	0.04d	0.12a	0.34a	0.05b	0.03a	0.30a	0.010b	8.37c	19.6a	0.03d
Rocky Mtn.	3	17	0.60a	0.06c	0.08ab	0.27b	0.02b	0.03a	0.30a	0.010b	277b	1.59b	0.12c
Rocky Mtn.	3	25	0.93a	0.12b	0.06bc	0.22b	0.07b	0.03a	0.30a	0.010b	555a	1.61b	0.19a
Rocky Mtn.	3	51	0.70a	0.15a	0.04c	0.14c	0.38a	0.03a	0.30a	0.013a	780a	1.75b	0.17b
Waterton	3	0	0.24c	0.04c	0.08a	0.38d	0.05d	0.03a	0.30a	0.01a	112d	3.73a	0.06e
Waterton	3	200	0.46bc	0.04c	0.07ab	0.46cd	0.05d	0.03a	0.30a	0.01a	298cd	1.54b	0.10d
Waterton	3	400	0.65ab	0.04c	0.07ab	0.60bc	0.05d	0.03a	0.30a	0.01a	489bc	1.15b	0.12cd
Waterton	3	600	0.80a	0.04c	0.06ab	0.65b	0.05d	0.03a	0.30a	0.01a	629ab	1.32b	0.14bc
Waterton	3	800	0.94a	0.04c	0.07ab	0.68b	0.11c	0.03a	0.30a	0.01a	787a	1.35b	0.14bc
Waterton	3	1200	0.64ab	0.05b	0.07ab	0.69b	0.24b	0.03a	0.30a	0.01a	696ab	1.60b	0.17ab
Waterton	3	2400	0.43bc	0.10a	0.05b	1.05a	0.58a	0.03a	0.30a	0.01a	810a	1.93b	0.18a
G. Prairie	3	0	0.18e	0.13b	0.15a	0.58a	0.05c	0.03b	0.30a	0.01a	26.0e	13.1a	0.03c
G. Prairie	3	65	1.51d	0.05c	0.14ab	0.56ab	0.05c	0.03b	0.30a	0.01a	732d	6.24d	0.11b
G. Prairie	3	204	2.01c	0.13b	0.11ab	0.51ab	0.05c	0.03b	0.30a	0.01a	1430c	9.10c	0.18a
G. Prairie	3	408	2.13b	0.26a	0.09ab	0.44b	0.33b	0.05a	0.30a	0.01a	2100b	11.9b	0.18a
G. Prairie	3	612	2.59a	0.27a	0.07b	0.25c	0.94a	0.03b	0.30a	0.01a	2580a	13.0a	0.11b

* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 39. Comparison of the saturated paste extract data (mean values) for the DAP waste/soil mixtures.

Location	Rep	Cl Rate kg/ha	Sat'n (%)	E.C. (dS/m)	SAR	pH	Cl	Alk	HCO3	CO3	OH	NO3	Al	Cr	Fe	V
							(mg/L)									
Cold Lake	3	0	34.2d*	0.31c	0.55d	6.33c	8.18c	106b	106b	0.02a	0.001c	0.03b	2.71a	0.02a	3.72a	0.03b
Cold Lake	3	10	34.0d	0.80bc	2.48d	6.95b	8.86c	203ab	202ab	0.17a	0.004bc	0.05b	0.97a	0.02a	0.42a	0.03b
Cold Lake	3	124	44.0c	4.21ab	17.8c	7.80a	101b	285a	283a	1.68a	0.031ab	153b	0.99a	0.02a	0.11a	0.03b
Cold Lake	3	249	62.3b	5.83a	28.1b	7.80a	166ab	206ab	205ab	0.39a	0.033a	420a	0.94a	0.02a	0.03a	0.04ab
Cold Lake	3	373	83.8a	7.12a	34.1a	7.85a	189a	177b	175b	0.16a	0.036a	487a	1.09a	0.02a	0.02a	0.05a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg $CaCO_3$/L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ti	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	B	Ba	P	Mo
	(mg/L)															
Cold Lake	0.35a	0.01a	0.07a	0.10a	0.13a	0.40a	52.7a	14.0a	17.3b	4.85c	0.08b	0.15a	0.09b	0.09a	0.46b	0.05b
Cold Lake	0.04a	0.01a	0.07a	0.10a	0.12a	0.36a	97.1a	22.7a	105b	4.50c	0.08b	0.27a	0.21b	0.09a	0.36b	0.05b
Cold Lake	0.02a	0.01a	0.07a	0.10a	0.21a	0.05a	162a	31.6a	943a	13.1bc	0.18b	1.03a	1.05b	0.10a	1.50b	0.70b
Cold Lake	0.01a	0.01a	0.05ab	0.10a	0.21a	0.07a	139a	28.0a	1370a	25.2ab	0.41b	1.30a	2.50a	0.07a	4.73a	1.48a
Cold Lake	0.02a	0.01a	0.03b	0.10a	0.22a	0.08a	154a	29.9a	1710a	32.2a	0.78a	1.84a	3.04a	0.08a	3.86a	2.11a

Location	Ni	Se	Co	S	Si	As
	(mg/L)					
Cold Lake	0.03b	0.30a	0.01a	27.9c	13.5a	0.06c
Cold Lake	0.03b	0.30a	0.01a	108bc	5.06ab	0.09bc
Cold Lake	0.08a	0.30a	0.01a	552ab	2.71b	0.14ab
Cold Lake	0.07ab	0.30a	0.01a	583a	6.05ab	0.16ab
Cold Lake	0.04ab	0.30a	0.01a	730a	5.16ab	0.17a

Table 40. Comparison of the saturated paste extract data (mean values) for the invert waste/soil mixtures.

Location	N	Cl Rate kg/ha	Sat'n (%)	E.C. (dS/m)	SAR	pH	Cl	Alk	HCO3	CO3	OH	NO3	Al	Cr
							(mg/L)							
Rocky Mtn.	3	0	43.2b*	0.11f	0.87d	5.48b	8.15e	18.9b	18.9b	0.001b	0.000b	0.63b	8.13a	0.02a
Rocky Mtn.	3	200	46.7ab	0.70ef	1.03cd	5.28b	223de	21.1b	21.1b	0.000b	0.000b	0.75b	1.08c	0.02a
Rocky Mtn.	3	400	47.3ab	1.29de	1.18bc	5.38b	411cde	19.5b	19.5b	0.000b	0.000b	0.67b	1.23bc	0.02a
Rocky Mtn.	3	600	47.8a	1.95cd	1.33bc	5.30b	652cd	11.5b	11.5b	0.000b	0.000b	9.23ab	1.41bc	0.02a
Rocky Mtn.	3	800	50.3a	2.47c	1.42b	5.27b	843c	28.6ab	28.6ab	0.000b	0.000b	2.15ab	1.67bc	0.02a
Rocky Mtn.	3	1200	48.5a	4.06b	1.82a	5.43b	1370b	27.9ab	27.9ab	0.001b	0.000b	23.0a	2.60bc	0.02a
Rocky Mtn.	3	2400	49.8a	7.07a	1.87a	6.03a	2520a	61.9a	61.9a	0.006a	0.001a	0.61b	3.27b	0.02a
G. Prairie	3	0	43.3d	0.25f	0.65g	5.48d	8.84e	58.6bc	58.6bc	1.70b	0.15d	0.08a	1.71c	0.02a
G. Prairie	3	200	44.8cd	0.92e	0.94f	5.73cd	222de	29.6c	29.6c	1.57b	0.28cd	0.07a	0.92d	0.02a
G. Prairie	3	400	47.0cd	1.68d	1.10e	5.63d	461d	33.8c	33.8c	1.39b	0.24d	3.72a	1.26d	0.02a
G. Prairie	3	600	47.3c	2.53c	1.29d	5.70cd	718c	37.4c	37.4c	1.76b	0.25d	32.3a	1.72c	0.02a
G. Prairie	3	800	48.2bc	2.99c	1.47c	5.95bc	925c	43.9bc	43.9bc	3.69b	0.44c	9.73a	1.96c	0.02a
G. Prairie	3	1200	51.3ab	4.10b	1.80b	6.15b	1350b	74.5b	74.5b	10.0b	0.71b	4.00a	2.55b	0.02a
G. Prairie	3	2400	54.2a	7.33a	2.63a	6.70a	2620a	151a	151a	71.3a	2.50a	0.19a	4.34a	0.02a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); SAR = Sodium Adsorption Ratio; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Fe	V	Ti	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	B
								(mg/L)							
Rocky Mtn.	8.21a	0.03a	0.50a	0.01a	0.04a	0.10a	0.14b	0.28d	9.1c	2.96d	11.8c	1.99d	0.04a	0.04c	0.04c
Rocky Mtn.	0.14b	0.03a	0.01b	0.01a	0.04a	0.10a	0.26ab	2.26cd	70.7bc	22.3cd	38.6c	4.09d	0.04a	0.36c	0.04c
Rocky Mtn.	0.13b	0.03a	0.01b	0.01a	0.05a	0.10a	0.31ab	4.52bcd	142.1bc	40.3cd	61.8c	4.99cd	0.04a	0.72bc	0.05bc
Rocky Mtn.	0.15b	0.03a	0.02b	0.01a	0.04a	0.10a	0.31ab	6.96abc	224.2bc	57.8cd	85.9c	9.04b	0.04a	1.10bc	0.07bc
Rocky Mtn.	0.22b	0.03a	0.02b	0.01a	0.03a	0.10a	0.39a	8.94ab	307.4bc	73.0bc	107bc	8.11bc	0.04a	1.49bc	0.08b
Rocky Mtn.	0.19b	0.03a	0.03b	0.01a	0.04a	0.10a	0.28ab	10.5a	708ab	124ab	198ab	13.2a	0.04a	3.21ab	0.14a
Rocky Mtn.	0.09b	0.03a	0.04b	0.01a	0.04a	0.10a	0.24ab	9.81a	1040a	160a	245a	13.5a	0.04a	4.51a	0.15a
G. Prairie	5.02a	0.03a	0.23a	0.01a	0.04a	0.10a	0.16ab	0.45e	37.4e	7.38f	16.7g	4.65f	0.04a	0.18e	0.13a
G. Prairie	0.20b	0.03a	0.01b	0.01a	0.01b	0.10a	0.24a	2.72d	127de	25.4e	44.5f	10.0e	0.04a	0.51de	0.13a
G. Prairie	0.15b	0.03a	0.01b	0.01a	0.01b	0.10a	0.17ab	5.41bc	235d	45.6d	70.2e	14.5d	0.04a	0.88d	0.13a
G. Prairie	0.13b	0.03a	0.02b	0.01a	0.01b	0.10a	0.10b	7.94a	370c	68.7c	103d	20.7c	0.04a	1.32c	0.13a
G. Prairie	0.09b	0.03a	0.02b	0.01a	0.01b	0.10a	0.10b	7.83a	449c	79.2c	128c	21.1c	0.04a	1.57c	0.14a
G. Prairie	0.07b	0.03a	0.03b	0.01a	0.01b	0.10a	0.10b	7.09ab	650b	102b	187b	26.2b	0.04a	2.23b	0.15a
G. Prairie	0.05b	0.03a	0.04b	0.01a	0.02ab	0.10a	0.08b	4.68cd	13340a	139a	378a	36.7a	0.04a	4.68a	0.14a

continued...

Table 40. Concluded.

Location	N	Cl Rate	Ba	P	Mo	Ni	Se	Co	S	Si	As
		kg/ha					(mg/L)				
Rocky Mtn.	3	0	0.12d*	0.34a	0.05a	0.03a	0.30a	0.01b	8.37b	19.6a	0.03a
Rocky Mtn.	3	200	0.79ab	0.10d	0.05a	0.03a	0.30a	0.03ab	10.9b	13.7ab	0.03a
Rocky Mtn.	3	400	0.81a	0.11d	0.05a	0.04a	0.30a	0.05ab	15.2b	13.7ab	0.03a
Rocky Mtn.	3	600	0.62bc	0.12d	0.05a	0.05a	0.30a	0.06a	22.7b	13.8ab	0.03a
Rocky Mtn.	3	800	0.44c	0.14cd	0.05a	0.06a	0.30a	0.06a	32.5b	12.9ab	0.03a
Rocky Mtn.	3	1200	0.24d	0.17bc	0.05a	0.05a	0.30a	0.04a	92.7ab	9.11b	0.04a
Rocky Mtn.	3	2400	0.23d	0.20b	0.05a	0.04a	0.30a	0.02ab	152a	7.45b	0.05a
G. Prairie	3	0	0.15c	0.58a	0.05a	0.03a	0.30a	0.01a	26.0f	13.1a	0.03b
G. Prairie	3	200	0.39ab	0.32bc	0.05a	0.03a	0.30a	0.01a	50.7e	11.7b	0.03b
G. Prairie	3	400	0.48a	0.27c	0.05a	0.03a	0.30a	0.01a	66.8de	10.7c	0.03b
G. Prairie	3	600	0.49a	0.30bc	0.05a	0.03a	0.30a	0.01a	85.0d	10.2c	0.03b
G. Prairie	3	800	0.40ab	0.27c	0.05a	0.03a	0.30a	0.01a	108c	8.48d	0.03b
G. Prairie	3	1200	0.32b	0.29bc	0.05a	0.03a	0.30a	0.01a	142b	6.66e	0.03b
G. Prairie	3	2400	0.29bc	0.41b	0.05a	0.03a	0.30a	0.01a	244a	4.44f	0.07a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 41. Comparison of the saturated paste extract data (mean values) for the KCl waste/soil mixtures.

Location	N	Cl Rate kg/ha	Sat'n (%)	E.C. (dS/m)	SAR	pH	Cl	Alk	HCO3	CO3	OH	NO3	Al	Cr	Fe
											(mg/L)				
Cold Lake	3	0	34.3a*	0.16f	1.02f	6.50b	7.95d	78.7c	78.7c	0.05d	0.003c	0.09a	3.05a	0.02a	19.3a
Cold Lake	3	200	34.0a	0.96ef	1.81e	6.57b	209d	138b	138b	0.05d	0.002c	0.12a	0.66b	0.02a	0.18b
Cold Lake	3	400	34.3a	1.86de	2.13de	6.95ab	702c	173ab	173ab	0.15cd	0.004bc	0.09a	1.00ab	0.02a	0.08b
Cold Lake	3	600	34.3a	2.56cd	2.50cd	7.03ab	672c	180a	179a	0.18cd	0.005bc	0.13a	1.26ab	0.02a	0.04b
Cold Lake	3	800	35.0a	3.43c	2.91c	7.13ab	966bc	186a	186a	0.24bc	0.007bc	0.10a	1.63ab	0.02a	0.02b
Cold Lake	3	1200	35.5a	4.88b	3.64b	7.33ab	1320b	180a	180a	0.36ab	0.011ab	0.15a	2.26ab	0.02a	0.02b
Cold Lake	3	2400	37.2a	10.5a	6.53a	7.47a	3130a	174ab	174a	0.48a	0.014a	0.35a	3.70ab	0.02a	0.02b
Waterton	3	0	68.8a	0.69f	0.36g	6.50b	7.43e	87.7b	87.7b	0.03b	0.002b	5.33a	0.69f	0.02a	0.07a
Waterton	3	200	70.0a	1.01ef	0.51f	6.52b	125de	87.6b	87.6b	0.03b	0.002b	3.90a	0.83ef	0.02a	0.04ab
Waterton	3	400	72.2a	1.51de	0.67e	6.48b	268cde	87.4b	87.4b	0.03b	0.002b	7.06a	1.10de	0.02a	0.04ab
Waterton	3	600	69.0a	2.10cd	0.87d	6.52b	427bcd	86.6b	86.5b	0.03b	0.002b	10.7a	1.41cd	0.02a	0.03b
Waterton	3	800	70.2a	2.43c	0.98c	6.57b	548bc	90.0b	90.1b	0.03b	0.002b	23.7a	1.54c	0.02a	0.03b
Waterton	3	1200	71.5a	3.40b	1.35b	6.60b	770b	93.0b	92.9b	0.03b	0.002b	28.3a	1.97b	0.02a	0.03b
Waterton	3	2400	71.3a	6.10a	2.21a	6.78a	1710a	120a	120a	0.07a	0.003a	34.7a	2.99a	0.02a	0.03b

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	V	Ti	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	B	Ba
								(mg/L)							
Cold Lake	0.05a	0.99a	0.01a	0.04a	0.10a	0.18a	0.30d	18.9g	5.29g	19.5e	5.87b	0.04a	0.08g	0.06b	0.10d
Cold Lake	0.03b	0.01b	0.01a	0.01b	0.10a	0.18a	1.34a	111f	26.2f	81.6de	19.1b	0.04a	0.26f	0.04b	0.16d
Cold Lake	0.03b	0.01b	0.01a	0.01b	0.10a	0.11a	1.02ab	224e	46.4e	134d	44.8b	0.04a	0.54e	0.04b	0.25c
Cold Lake	0.03b	0.01b	0.01a	0.01b	0.10a	0.09a	0.75bc	307d	60.2d	183cd	70.3b	0.04a	0.77d	0.04b	0.29bc
Cold Lake	0.03b	.0.01b	0.01a	0.01b	0.10a	0.11a	0.55cd	417c	75.9c	247c	107b	0.04a	1.06c	0.04b	0.32bc
Cold Lake	0.03b	0.01b	0.01a	0.01b	0.10a	0.10a	0.38cd	590b	96.0b	363b	208b	0.04a	1.55b	0.04b	0.34b
Cold Lake	0.03b	0.02b	0.01a	0.01b	0.10a	0.16a	0.49cd	1050a	143a	854a	915a	0.04a	2.76a	0.09a	0.50a
Waterton	0.03a	0.010d	0.01a	0.03a	0.10a	0.073ab	0.02c	134d	23.2d	16.9e	4.00e	0.04a	0.24e	0.04a	0.07e
Waterton	0.03a	0.010d	0.01a	0.02a	0.10a	0.070ab	0.02c	178d	31.0d	27.9de	6.28de	0.04a	0.33e	0.04a	0.09de
Waterton	0.03a	0.012cd	0.01a	0.02a	0.10a	0.073ab	0.06c	255cd	43.7cd	43.6d	11.4de	0.04a	0.49de	0.04a	0.11cde
Waterton	0.03a	0.018bc	0.01a	0.02a	0.10a	0.066b	0.15bc	349c	59.6c	66.6c	18.3cd	0.04a	0.68cd	0.04a	0.13cd
Waterton	0.03a	0.018b	0.01a	0.02a	0.10a	0.103ab	0.22bc	390c	66.1c	79.7c	26.1c	0.04a	0.79c	0.04a	0.15bc
Waterton	0.03a	0.021b	0.01a	0.02a	0.10a	0.110ab	0.34b	542b	89.2b	129b	48.3b	0.04a	1.16b	0.04a	0.18b
Waterton	0.03a	0.031a	0.01a	0.02a	0.10a	0.122a	0.78a	963a	143a	277a	158a	0.04a	2.32a	0.04a	0.24a

continued...

Table 41. Concluded.

Location	N	Cl Rate kg/ha	P	Mo	Ni	Se	Co	S	Si	As
			(mg/L)							
Cold Lake	3	0	0.57a*	0.05a	0.03a	0.30a	0.01a	3.75f	19.1a	0.06ab
Cold Lake	3	200	0.19bc	0.05a	0.03a	0.30a	0.01a	32.8ef	5.43b	0.05b
Cold Lake	3	400	0.17c	0.05a	0.03a	0.30a	0.01a	63.1de	3.38b	0.06ab
Cold Lake	3	600	0.16c	0.05a	0.03a	0.30a	0.01a	85.1cd	2.56b	0.06ab
Cold Lake	3	800	0.17c	0.05a	0.03a	0.30a	0.01a	121c	2.09b	0.06ab
Cold Lake	3	1200	0.20bc	0.05a	0.03a	0.30a	0.01a	176b	2.07b	0.06ab
Cold Lake	3	2400	0.26b	0.05a	0.03a	0.30a	0.01a	400a	3.84b	0.07a
Waterton	3	0	0.38a	0.05a	0.03a	0.30a	0.01a	122b	3.73a	0.06b
Waterton	3	200	0.36ab	0.05a	0.03a	0.30a	0.01a	115b	3.07ab	0.06b
Waterton	3	400	0.34bc	0.05a	0.03a	0.30a	0.01a	124b	2.80b	0.06b
Waterton	3	600	0.32bc	0.05a	0.03a	0.30a	0.01a	140b	2.36bc	0.06b
Waterton	3	800	0.33bc	0.05a	0.03a	0.30a	0.01a	131b	2.60bc	0.06b
Waterton	3	1200	0.30c	0.05a	0.03a	0.30a	0.01a	150b	2.04c	0.06b
Waterton	3	2400	0.35abc	0.05a	0.03a	0.30a	0.01a	222a	1.30d	0.08a

* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 42. Comparison of the saturated paste extract data (mean values) for the NaCl waste/soil mixtures.

Location	N	Cl Rate kg/ha	Sat'n (%)	E.C. (dS/m)	SAR	pH	Cl	Alk	HCO3	CO3	OH	NO3	Al	Cr
											(mg/L)			
Cold Lake	3	0	34.3ab*	0.16e	1.02e	6.50ab	7.95e	78.7c	78.7c	0.05c	0.003ab	0.09b	3.05a	0.02a
Cold Lake	3	200	35.0ab	0.57e	2.82de	6.30b	126de	99.2c	99.2c	0.02c	0.001b	0.11ab	0.62b	0.02a
Cold Lake	3	400	33.8b	1.36de	4.19cd	6.45ab	363de	141bc	141bc	0.04c	0.001b	0.17a	0.48b	0.02a
Cold Lake	3	600	34.5ab	2.07cde	5.16cd	6.57ab	559cde	164abc	164abc	0.06c	0.002b	0.13ab	0.68b	0.02a
Cold Lake	3	800	33.3b	3.24bcd	6.61bc	6.90ab	897bcd	186ab	186ab	0.14bc	0.004ab	0.17a	0.98ab	0.02a
Cold Lake	3	1200	35.3ab	4.30bc	8.21b	7.03ab	1260bc	204ab	204ab	0.21b	0.005ab	0.12ab	1.36ab	0.02a
Cold Lake	3	1520	37.1a	4.81b	8.94b	7.13ab	1410b	209ab	208ab	0.27b	0.007ab	0.13ab	1.46ab	0.02a
Cold Lake	3	2400	33.2b	7.66a	13.7a	7.28a	2490a	241a	241a	0.43a	0.01a	0.09b	2.11ab	0.02a
Slave Lake	3	0	37.7c	0.40g	0.85g	5.35f	11.5g	63.6b	63.6b	1.38d	0.11e	0.15b	2.28e	0.02a
Slave Lake	3	200	38.8abc	2.00f	7.75f	5.87e	278f	132b	132b	9.21d	0.37e	0.06b	2.01f	0.02a
Slave Lake	3	400	38.5bc	3.80e	2.67e	6.40d	678e	230a	230a	54.3d	1.26de	0.07b	2.87d	0.02a
Slave Lake	3	600	39.7abc	4.83d	3.39d	6.70c	984d	296a	296a	139c	2.50cd	0.07b	3.32c	0.02a
Slave Lake	3	800	41.2ab	5.52c	4.08c	6.80c	1250c	293a	292a	173c	3.15c	0.07b	3.46c	0.02a
Slave Lake	3	1200	39.8abc	7.33b	5.91b	7.05b	1980b	288a	288a	303b	5.63b	0.14b	3.95b	0.02a
Slave Lake	3	2400	41.3a	12.2a	10.9a	7.25a	3930a	250a	250a	418a	8.93a	46.0a	4.67a	0.02a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Fe	V	Ti	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr
								(mg/L)						
Cold Lake	19.3a	0.05a	0.99a	0.01a	0.04a	0.10a	0.18a	0.30a	18.9f	5.29e	19.5d	5.87cd	0.04a	0.08f
Cold Lake	1.11b	0.03a	0.09b	0.01a	0.02b	0.10a	0.21a	0.95a	44.8ef	11.4e	81.8d	5.04d	0.04a	0.10f
Cold Lake	0.06b	0.03a	0.01b	0.01a	0.01b	0.10a	0.19a	1.65a	104ef	23.0de	181cd	6.38cd	0.04a	0.22ef
Cold Lake	0.04b	0.03a	0.01b	0.01a	0.01b	0.10a	0.21a	1.94a	158de	39.2cd	280bcd	7.37bcd	0.04a	0.32de
Cold Lake	0.03b	0.03a	0.01b	0.01a	0.01b	0.10a	0.20a	1.55a	232cd	54.5bc	432bcd	8.79bcd	0.04a	0.46cd
Cold Lake	0.03b	0.03a	0.01b	0.01a	0.01b	0.10a	0.24a	0.96a	323bc	69.9ab	627bc	10.6abc	0.04a	0.63bc
Cold Lake	0.04b	0.03a	0.01b	0.01a	0.01b	0.10a	0.22a	0.89a	360b	74.4ab	715b	12.1ab	0.04a	0.69b
Cold Lake	0.07b	0.03a	0.01b	0.01a	0.01b	0.10a	0.21a	1.61a	502a	90.0a	1280a	13.76a	0.04a	0.93a
Slave Lake	3.03a	0.03a	0.13a	0.01a	0.03ab	0.10a	0.21ab	1.12c	59.2f	10.7f	27.1f	6.08b	0.04a	0.20f
Slave Lake	1.00b	0.03a	0.02b	0.01a	0.01b	0.10a	0.19ab	5.15a	336e	55.7e	131e	7.33b	0.04a	0.77e
Slave Lake	0.53bc	0.03a	0.03b	0.01a	0.02ab	0.10a	0.18ab	6.35a	687d	98.0d	283d	6.77b	0.04a	1.53d
Slave Lake	0.31bc	0.03a	0.03b	0.01a	0.02ab	0.10a	0.13b	5.26a	882c	112c	402c	9.94b	0.04a	2.00c
Slave Lake	0.25c	0.03a	0.03b	0.01a	0.02ab	0.10a	0.14b	4.31ab	949c	120c	502c	10.9b	0.04a	2.25c
Slave Lake	0.13c	0.03a	0.04b	0.01a	0.04ab	0.10a	0.20ab	2.36bc	1110b	144b	790b	14.9b	0.04a	2.95b
Slave Lake	0.12c	0.03a	0.04b	0.01a	0.05a	0.10a	0.25a	1.82c	1430a	222a	1680a	35.0a	0.04a	4.99a

continued...

Table 42. Concluded.

Location	N	Cl Rate kg/ha	B	Ba	P	Mo	Ni	Se (mg/L)	Co	S	Si	As
Cold Lake	3	0	0.06a*	0.10e	0.57a	0.05a	0.03a	0.30a	0.01a	3.75d	19.1a	0.06bcd
Cold Lake	3	200	0.04b	0.09e	0.20c	0.05a	0.03a	0.30a	0.01a	4.76d	7.56b	0.03d
Cold Lake	3	400	0.04b	0.15de	0.18c	0.05a	0.03a	0.30a	0.01a	2.6cd	5.22b	0.05cd
Cold Lake	3	600	0.04b	0.20cd	0.18c	0.05a	0.03a	0.30a	0.01a	21.6bcd	4.48b	0.08bcd
Cold Lake	3	800	0.04b	0.25bc	0.19c	0.05a	0.03a	0.30a	0.01a	37.3bcd	3.48b	0.09abc
Cold Lake	3	1200	0.04b	0.28bc	0.20c	0.05a	0.03a	0.30a	0.01a	53.0abc	3.01b	0.10ab
Cold Lake	3	1520	0.04b	0.31ab	0.19c	0.05a	0.03a	0.30a	0.01a	62.4ab	2.93b	0.10ab
Cold Lake	3	2400	0.04b	0.36a	0.39b	0.05a	0.03a	0.30a	0.01a	90.8a	4.28b	0.13a
Slave Lake	3	0	0.19b	0.19b	0.54a	0.05a	0.03a	0.30a	0.01a	47.5e	11.6a	0.06c
Slave Lake	3	200	0.14c	0.22b	0.42a	0.05a	0.03a	0.30a	0.01a	264d	8.04b	0.03c
Slave Lake	3	400	0.13c	0.27ab	0.47a	0.05a	0.03a	0.30a	0.01a	483c	6.29bc	0.08bc
Slave Lake	3	600	0.12c	0.26b	0.47a	0.05a	0.03a	0.30a	0.01a	557b	5.17cd	0.12ab
Slave Lake	3	800	0.13c	0.24b	0.42a	0.05a	0.03a	0.30a	0.01a	569b	8.09cd	0.12ab
Slave Lake	3	1200	0.15bc	0.23b	0.47a	0.05a	0.03a	0.30a	0.01a	589ab	3.98d	0.15a
Slave Lake	3	2400	0.24a	0.36a	0.46a	0.05a	0.03a	0.30a	0.01a	623a	3.62d	0.16a

* Treatment means in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

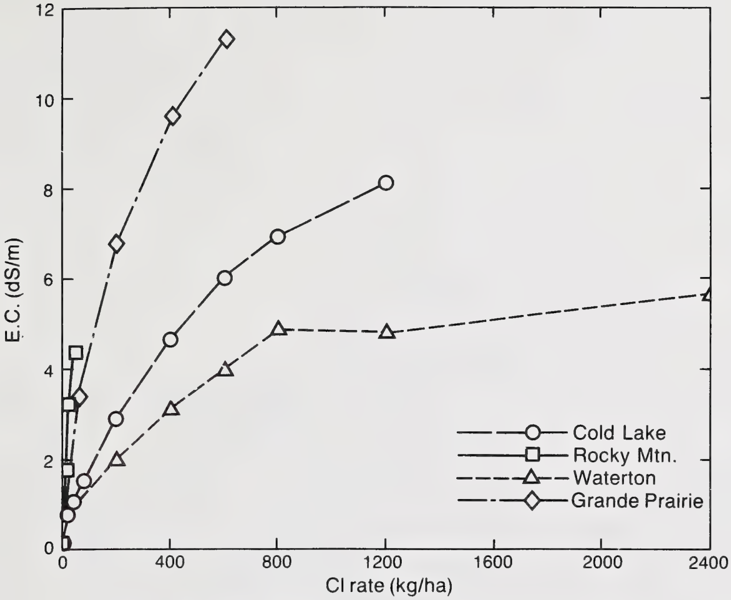


Figure 33. Mean electrical conductivity (EC) values for the freshwater gel waste/soil mixtures.

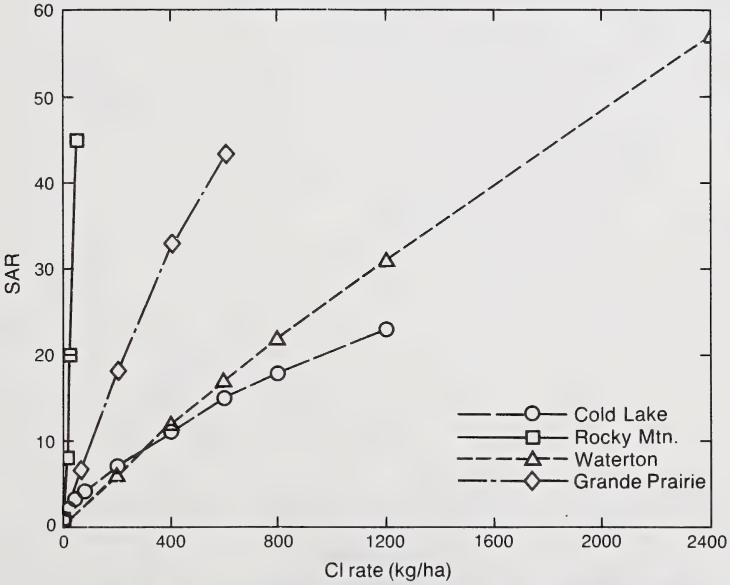


Figure 34. Mean sodium adsorption ratio (SAR) values for the freshwater gel waste/soil mixtures.

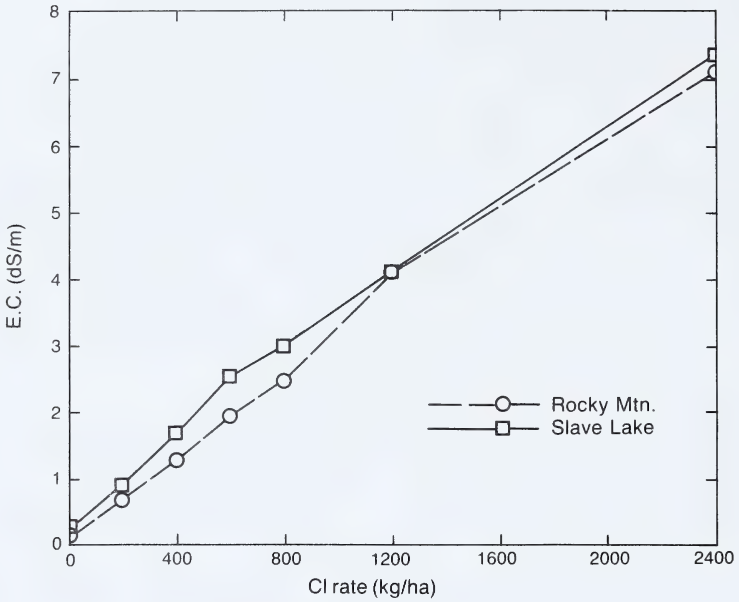


Figure 35. Mean electrical conductivity (EC) values for the invert waste/soil mixtures.

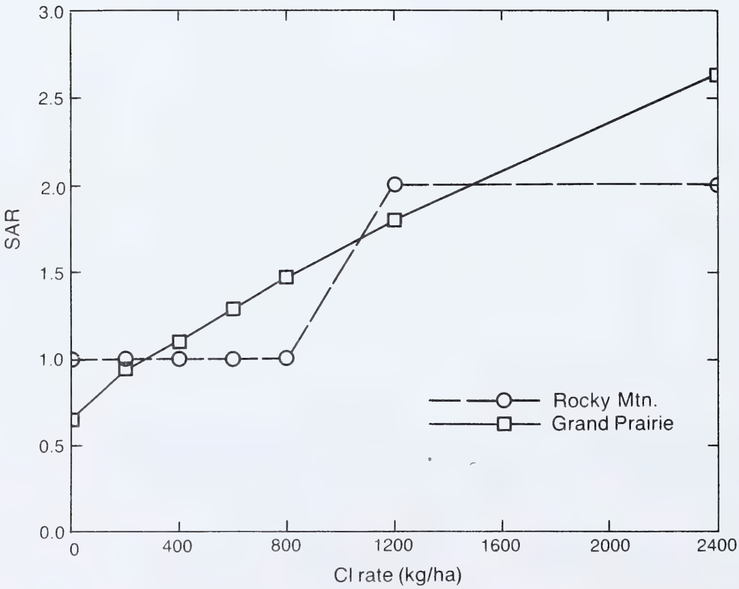


Figure 36. Mean sodium adsorption ratio (SAR) values for the invert waste/soil mixtures.

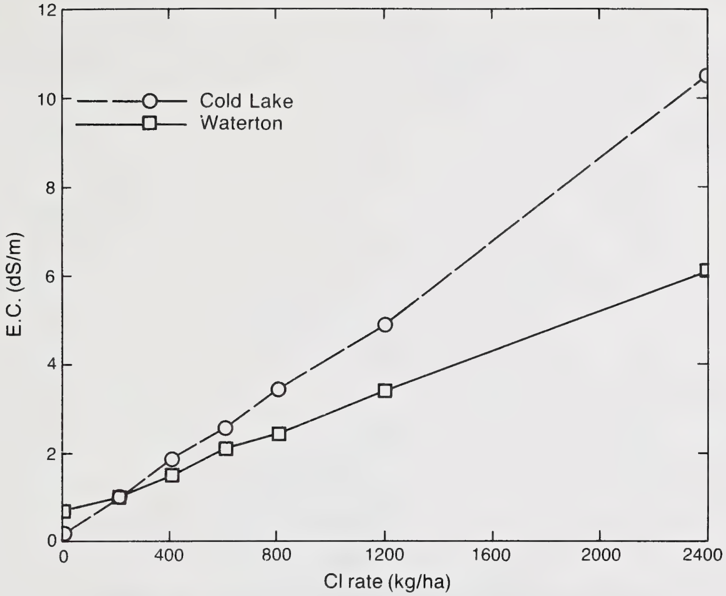


Figure 37. Mean electrical conductivity (EC) values for the KCl waste/soil mixtures.

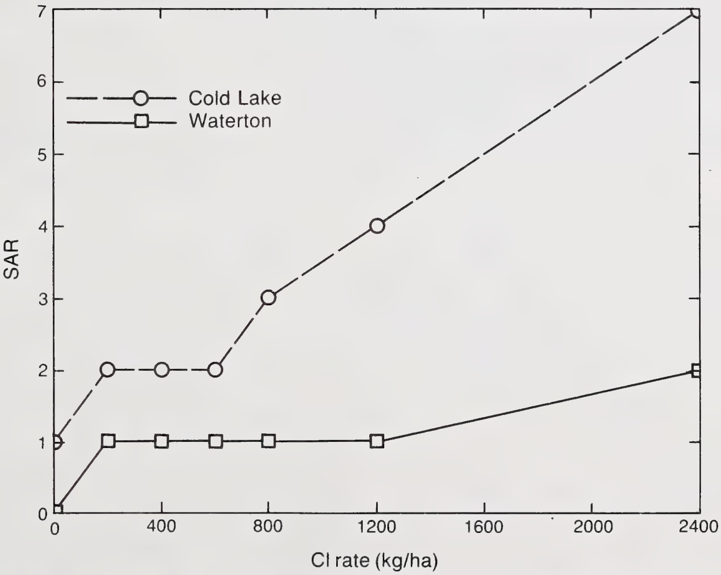


Figure 38. Mean sodium adsorption ratio (SAR) values for the KCl waste/soil mixtures.

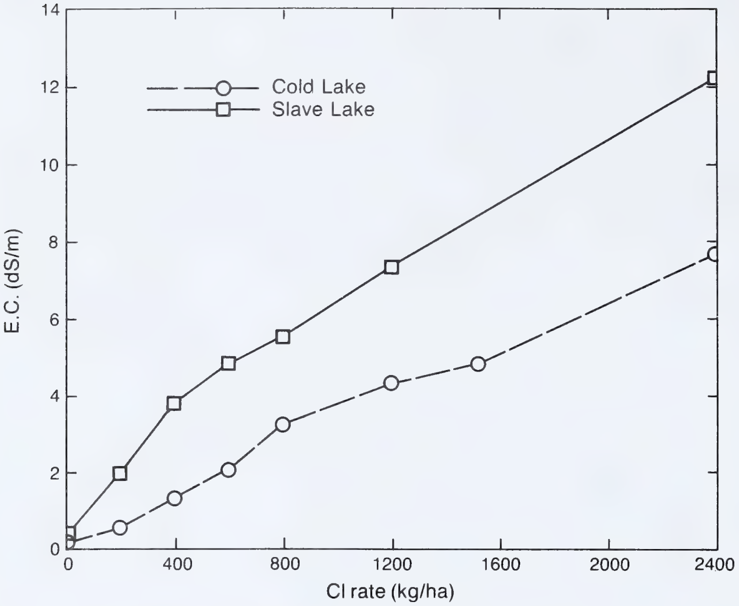


Figure 39. Mean electrical conductivity (EC) values for the NaCl waste/soil mixtures.

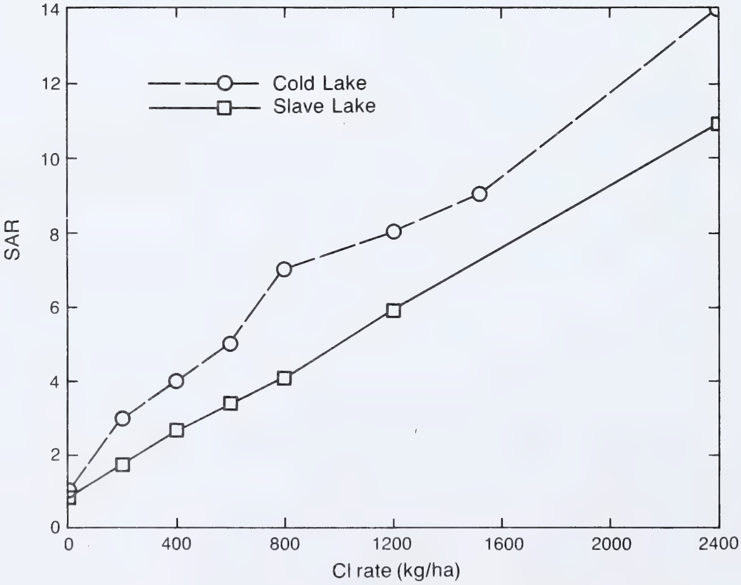


Figure 40. Mean sodium adsorption ratio (SAR) values for the NaCl waste/soil mixtures.

Table 43. Ranking of waste application rates on the basis of kg Cl/ha according to criteria for EC.

		Limitation[a]			
Waste Type	Location	No	Slight	Moderate	Severe
Freshwater gel	Cold Lake	80[b]	200	800	1200
Freshwater gel	Rocky Mtn House	17	25	51	NA[d]
Freshwater gel	Waterton	200	600	2400	NA
Freshwater gel	Grande Prairie	L[c]	65	204	408
DAP	Cold Lake	10	124	373	NA
Invert	Rocky Mtn House	600	1200	2400	NA
Invert	Grande Prairie	400	800	1200	NA
KCl	Cold Lake	400	800	1200	2400
KCl	Waterton	400	1200	2400	NA
NaCl	Cold Lake	400	800	2400	NA
NaCl	Red Earth Creek	200	400	1200	2400

[a] No limitation - <2 dS/m
Slight limitation - 2 to 4 dS/m
Moderate limitation - 4 to 8 dS/m
Severe limitation - >8 dS/m.

[b] 80 = 80 kg Cl/ha rate.

[c] L = Limitation with all rates used.

[d] NA = Limitation not achieved with rates used.

The SAR values suggested that potential limitations may occur with increasing concentration of freshwater gel, DAP, and NaCl waste application. The Alberta Soils Advisory Committee (1977) presented the following criteria for SAR levels in soil:

	SAR Value
No limitation	<4
Slight limitation	4 to 8
Moderate limitation	8 to 12
Severe limitation	>12

Interpretations relative to the impact of waste application on the suitability of the waste/soil mixtures for plant growth as measured by SAR are presented in Table 44. For example the maximum rate of 2400 kg Cl/ha of invert waste could be added without any resulting limitation utilizing SAR as the criteria for application.

Maas (1986) indicated that the maximum chloride content that could be present in saturated extracts without loss in yield for grasses ranges from 1000 to 2600 ppm. If one selected the lower range value of 1000 ppm as the level at which chloride content begins to impact yield then rates in excess of 800 kg Cl/ha for the invert (Grande Prairie and Rocky Mountain House), NaCl and KCl (Cold Lake) wastes could be considered limiting because of chloride concentration in the resulting soil/waste medium.

5.7 DTPA EXTRACT DATA FOR THE WASTE/SOIL MIXTURES

A comparison of the mean values for the DTPA extract data is presented in Tables 45 to 49. Generally, as DTPA extractable element content increases plant uptake of that element increases. Changes for the specific elements varied largely on the basis of waste type. Significant changes in the freshwater gel waste/soil mixtures from all sample locations occurred for Fe, Cu, Pb, Zn, Ca, Mg, Na, and K. Significant changes in the levels of Bo, P, Mo, Ni, and Se occurred from selected locations.

Significant changes in Fe, Cu, Pb, Zn, Mn, Ca, Na, K, B, P, Mo, and Ni occurred relative to the DAP waste/soil mixtures. The

Table 44. Ranking of waste application rates on the basis of kg Cl/ha according to criteria for SAR.

		Limitation[a]			
Waste Type	Location	No	Slight	Moderate	Severe
Freshwater gel	Cold Lake	80[b]	200	200	600
Freshwater gel	Rocky Mtn House	L[c]	17	>17, <25	>25
Freshwater gel	Waterton	<200	200	400	600
Freshwater gel	Grande Prairie	L	65	204	408
DAP	Cold Lake	10	>10	>10	>10
Invert	Rocky Mtn House	2400	NA[d]	NA	NA
Invert	Grande Prairie	2400	NA	NA	NA
KCl	Cold Lake	200	1200	2400	NA
KCl	Waterton	2400	NA	NA	NA
NaCl	Cold Lake	200	1200	1200	2400
NaCl	Red Earth Creek	600	1200	2400	NA

[a] No limitation - <4
Slight limitation - 4 to 8
Moderate limitation - 8 to 12
Severe limitation - >12.

[b] 80 = 80 kg Cl/ha rate.
[c] L = Limitation with all rates used.
[d] NA = Limitation not achieved with rates used.

Table 45. Comparison of the DTPA extract data (mean values) for the freshwater gel waste/soil mixtures.

Location	Cl Rate kg/ha	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo
									(ug/g)						
Cold Lake	0	3	51.0e*	0.1a	0.43g	0.30e	0.43e	4.13c	442a	146a	22.4f	85.0e	0.10d	7.00ef	0.20c
Cold Lake	20	3	39.5e	0.1a	0.47fg	0.47e	0.63de	2.80d	450a	127ab	58.2f	64.0f	0.10d	8.87de	0.20c
Cold Lake	40	3	40.6e	0.1a	0.53fg	0.77e	1.07de	2.67d	451a	110b	85.7f	59.2f	0.10d	10.6dc	0.20c
Cold Lake	80	3	47.3e	0.1a	0.73f	1.47e	1.40de	3.07d	438a	134ab	163f	71.7ef	0.10d	11.7bc	0.20c
Cold Lake	200	3	75.3d	0.1a	1.27e	3.30d	2.10d	4.37c	396a	138a	369e	87.3e	0.30d	14.5a	0.13c
Cold Lake	400	3	111c	0.1a	2.17d	6.47c	4.33c	5.90b	368a	148a	720d	121d	0.63c	13.1ab	0.20c
Cold Lake	600	3	129bc	0.1a	2.73c	8.67b	5.10bc	6.67b	346d	146a	1090c	157c	0.90b	10.8cd	0.40b
Cold Lake	800	3	135b	0.1a	3.33b	9.77b	6.10b	6.80b	328e	145a	1500b	206b	1.10b	8.90de	0.50b
Cold Lake	1200	3	171a	0.1a	4.53a	12.6a	10.0a	8.30a	273f	134ab	2178a	289a	1.63a	6.03f	0.87a
Rocky Mtn.	0	3	183a	0.25a	1.00c	1.25d	1.00c	12.0a	284b	72.1b	9.67d	45.1c	0.25a	8.58a	0.25a
Rocky Mtn.	17	3	102b	0.25a	2.00c	3.50c	1.42bc	4.50a	365a	67.9b	448c	56.1c	0.25a	7.50a	0.25a
Rocky Mtn.	25	3	96.4b	0.25a	3.67b	7.27b	3.75b	5.58a	359a	54.3c	1000b	105b	0.25a	7.17a	0.25a
Rocky Mtn.	51	3	79.3c	0.25a	5.50a	9.42a	15.92a	5.00a	269b	106a	1460a	169a	0.25a	7.00a	0.25a
Waterton	0	3	230a	0.25a	1.50f	1.75f	2.75g	2.92c	338bc	141a	17.5g	132d	0.25a	8.25a	0.25b
Waterton	200	3	215a	0.25a	1.92e	3.50ef	4.00f	3.25c	361ab	138a	568f	144d	0.25a	8.92a	0.25b
Waterton	400	3	204ab	0.25a	2.17de	4.75de	5.00e	6.08c	371a	114b	1160e	162d	0.25a	9.67a	0.25b
Waterton	600	3	194ab	0.25a	2.50cd	6.67cd	6.58d	9.29c	364a	104bc	1730d	166cd	0.25a	9.67a	0.25b
Waterton	800	3	187ab	0.25a	2.83c	8.58c	7.92c	12.0c	356ab	96.3cd	2270c	201c	0.25a	10.3a	0.25b
Waterton	1200	3	190ab	0.25a	3.50b	14.0b	11.6b	30.3b	322cd	101cd	3500b	280b	0.25a	10.3a	0.25b
Waterton	2400	3	141b	0.25a	5.08a	24.4a	17.5a	50.6a	301d	89.8d	7200a	446a	0.25a	9.67a	1.00a
G. Prairie	0	3	241a	0.11a	1.37e	1.00b	1.94d	10.3b	248ab	114a	17.4e	119c	0.10c	11.0bc	0.13c
G. Prairie	65	3	228a	0.10ab	1.93d	2.03b	1.78d	5.05d	262a	121a	495d	123bc	0.10c	13.9ab	0.13c
G. Prairie	204	3	227a	0.09bc	3.33c	3.43ab	3.56c	10.4b	248ab	103a	1670c	149b	0.10c	15.1a	0.13c
G. Prairie	408	3	226a	0.08cd	5.15b	5.26ab	6.71b	14.3a	210b	118a	3370b	187a	0.18b	12.5abc	0.25b
G. Prairie	612	3	180b	0.06d	5.71a	16.6a	10.7a	7.66c	163c	68.2b	4410a	194a	0.36a	9.06c	0.65a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

continued...

Table 45. Concluded.

Location	Cl Rate kg/ha	N	Ni	Se
			— (ug/g)	—
Cold Lake	0	3	0.60c*	0.8a
Cold Lake	20	3	0.80bc	0.8a
Cold Lake	40	3	1.10ab	0.8a
Cold Lake	80	3	1.17a	0.8a
Cold Lake	200	3	0.50c	0.8a
Cold Lake	400	3	0.73c	0.8a
Cold Lake	600	3	0.67c	0.8a
Cold Lake	800	3	0.70c	0.8a
Cold Lake	1200	3	0.70c	0.8a
Rocky Mtn.	0	3	0.50b	0.83a
Rocky Mtn.	17	3	0.25c	0.75a
Rocky Mtn.	25	3	0.50b	0.83a
Rocky Mtn.	51	3	1.50a	1.00a
Waterton	0	3	1.50a	0.75d
Waterton	200	3	1.42a	0.92cd
Waterton	400	3	1.25a	0.83cd
Waterton	600	3	1.25a	1.08cd
Waterton	800	3	1.33a	1.25c
Waterton	1200	3	1.42a	1.75b
Waterton	2400	3	1.33a	2.58a
G. Prairie	0	3	1.34a	0.81b
G. Prairie	65	3	1.11a	0.75b
G. Prairie	204	3	1.64a	0.75b
G. Prairie	408	3	2.12a	1.03a
G. Prairie	612	3	1.63a	1.00

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* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 46. Comparison of the DTPA extract data (mean values) for the DAP waste/soil mixtures.

Location	Cl Rate kg/ha	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni
									(ug/g)							
Cold Lake	0	3	137a*	0.25a	0.50c	0.67d	0.50e	2.17b	370ab	173a	8.5d	67.9d	0.25c	15.4b	0.25c	0.25d
Cold Lake	10	3	119b	0.25a	0.50c	1.50d	1.17d	1.75b	400a	157a	78.2d	66.1d	0.50c	18.6b	0.25c	0.42d
Cold Lake	124	3	106c	0.25a	1.50b	9.67c	4.33c	1.92b	378ab	177a	970c	130c	0.75bc	50.6a	0.25c	1.67c
Cold Lake	249	3	92.1d	0.25a	2.17ab	17.5b	8.42b	7.67a	362ab	182a	1970b	228b	1.50ab	60.2a	0.92b	3.00b
Cold Lake	373	3	78.3e	0.25a	2.83a	22.9a	12.3a	7.75a	321b	168a	2950a	298a	1.83a	52.3a	1.50a	3.58a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Se (ug/g)
Cold Lake	0	0.75a
Cold Lake	10	0.75a
Cold Lake	124	0.75a
Cold Lake	249	0.92a
Cold Lake	373	0.92a

Table 47. Comparison of the DTPA extract data (mean values) for the invert waste/soil mixtures.

Location	Cl Rate kg/ha	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca (ug/g)	Mg	Na	K	B	P	Mo
Rocky Mtn.	0	3	183a*	0.25a	1.00a	1.25c	1.00e	12.0c	283a	72.1d	9.67e	45.1e	0.25a	8.58a	0.25a
Rocky Mtn.	200	3	172a	0.25a	1.00a	1.50bc	1.25d	17.2bc	338a	87.3cd	29.5e	59.1de	0.25a	8.50a	0.25a
Rocky Mtn.	400	3	173a	0.25a	1.01a	1.50bc	1.58c	22.7ab	341a	101bc	50.3d	67.4cd	0.25a	8.75a	0.25a
Rocky Mtn.	600	3	161ab	0.25a	1.00a	1.50bc	1.75c	25.3ab	318a	102bc	64.4cd	81.8bc	0.25a	8.33a	0.25a
Rocky Mtn.	800	3	160ab	0.25a	1.00a	1.50bc	1.75c	27.8a	316a	107b	79.7c	77.8bcd	0.25a	8.08a	0.25a
Rocky Mtn.	1200	3	143bc	0.25a	1.00a	1.75ab	2.00b	26.3ab	313a	117ab	116b	92.3ab	0.25a	8.08a	0.25a
Rocky Mtn.	2400	3	116c	0.25a	1.00a	1.92a	2.50a	18.3bc	326a	128a	195a	103a	0.25a	7.42a	0.25a
G. Prairie	0	3	241a	0.11a	1.37a	1.00b	1.94a	10.3e	248a	114ab	17.4e	120b	0.10a	11.0a	0.13a
G. Prairie	200	3	250a	0.12a	1.36a	1.02b	1.90a	43.1c	211a	113ab	35.3e	130b	0.10a	11.7a	0.13a
G. Prairie	400	3	219a	0.10a	1.50a	0.78b	1.96a	48.7bc	196a	107ab	47.3de	129b	0.10a	10.1a	0.13a
G. Prairie	600	3	257a	0.13a	1.56a	1.14b	2.38a	59.6a	223a	134a	76.8cd	169a	0.10a	12.2a	0.16a
G. Prairie	800	3	237a	0.12a	1.45a	1.08b	2.16a	54.0ab	235a	135a	94.4bc	167a	0.10a	11.4a	0.13a
G. Prairie	1200	3	214ab	0.11a	1.49a	1.14b	2.08a	42.0c	232a	125ab	124b	166a	0.10a	11.4a	0.13a
G. Prairie	2400	3	163b	0.08b	1.54a	1.40a	2.26a	28.0d	241a	105b	221a	168a	0.10a	10.6a	0.15a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Ni (ug/g)	Se
Rocky Mtn.	0	0.50a	0.83a
Rocky Mtn.	200	0.50a	1.00a
Rocky Mtn.	400	0.50a	1.00a
Rocky Mtn.	600	0.50a	0.92a
Rocky Mtn.	800	0.50a	0.92a
Rocky Mtn.	1200	0.33ab	1.00a
Rocky Mtn.	2400	0.25b	0.92a
G. Prairie	0	1.34abc	0.81d
G. Prairie	200	1.46ab	1.84abc
G. Prairie	400	1.12bc	1.78abc
G. Prairie	600	1.60a	2.40a
G. Prairie	800	1.48ab	2.08ab
G. Prairie	1200	1.37abc	1.59bc
G. Prairie	2400	1.03c	1.21cd

Table 48. Comparison of the DTPA extract data (mean values) for the KCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo
									(ug/g)						
Cold Lake	0	3	51.0a*	0.1a	0.43c	0.30c	0.43c	4.13bc	442a	146a	22.4d	85.0c	0.10a	7.00c	0.20a
Cold Lake	200	3	42.2ab	0.1a	0.43c	0.33c	0.47d	4.40b	430ab	140a	56.2cd	125c	0.10a	7.60bc	0.20a
Cold Lake	400	3	38.9b	0.1a	0.47bc	0.43c	0.70cd	3.23cd	427ab	131a	72.3cd	187bc	0.10a	9.03bc	0.20a
Cold Lake	600	3	35.3b	0.1a	0.47bc	0.40c	0.83cd	2.90d	421ab	135a	99.0bcd	244bc	0.10a	8.57bc	0.20a
Cold Lake	800	3	36.7b	0.1a	0.57bc	0.50c	1.13bc	2.93d	407b	138a	136bc	319bc	0.10a	8.93bc	0.20a
Cold Lake	1200	3	39.1b	0.1a	0.67b	0.80b	1.63b	3.27cd	425ab	129a	182b	459b	0.10a	9.90b	0.20a
Cold Lake	2400	3	48.9a	0.1a	0.97a	1.77a	4.23a	5.70a	417ab	111a	414a	1290a	0.17a	12.7a	0.20a
Waterton	0	3	230a	0.25a	1.50a	1.75f	2.75f	2.92d	338b	141b	17.5f	132f	0.25a	8.25a	0.25a
Waterton	200	3	228a	0.25a	1.50a	2.00ef	3.42e	3.42d	341ab	146ab	50.2e	180ef	0.25a	9.08a	0.25a
Waterton	400	3	224a	0.25a	1.50a	2.17de	3.67e	3.25d	344ab	142ab	58.7e	204de	0.25a	9.00a	0.25a
Waterton	600	3	227a	0.25a	1.67a	2.33cd	4.33d	4.17cd	364ab	147ab	77.8d	253cd	0.25a	8.50a	0.25a
Waterton	800	3	215a	0.25a	1.50a	2.50bc	4.83c	5.92c	371a	152a	101c	307c	0.25a	8.50a	0.25a
Waterton	1200	3	215a	0.25a	1.50a	2.75b	5.75b	9.08b	364ab	147ab	139b	408b	0.25a	8.67a	0.25a
Waterton	2400	3	194a	0.25a	1.50a	3.42a	8.25a	13.3a	366ab	143ab	252a	734a	0.25a	8.75a	0.25a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Ni	Se
		(ug/g)	
Cold Lake	0	0.60a	0.8a
Cold Lake	200	0.20a	0.8a
Cold Lake	400	0.20a	0.8a
Cold Lake	600	0.20a	0.8a
Cold Lake	800	0.20a	0.8a
Cold Lake	1200	0.27a	0.8a
Cold Lake	2400	0.73a	0.8a
Waterton	0	1.50a	0.75b
Waterton	200	1.50a	0.75b
Waterton	400	1.50a	0.75b
Waterton	600	1.42a	0.92ab
Waterton	800	1.42a	1.00ab
Waterton	1200	1.33a	1.00ab
Waterton	2400	1.25a	1.17a

Table 49. Comparison of the DTPA extract data (mean values) for the NaCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo
			(ug/g)												
Cold Lake	0	3	51.0a*	0.1a	0.43a	0.30c	0.43abc	4.13a	442a	146a	22.4e	85.0a	0.10a	7.00b	0.20a
Cold Lake	200	3	52.0a	0.1a	0.43a	0.47abc	0.47abc	6.20a	414b	124ab	69.8e	63.7b	0.10a	8.10b	0.20a
Cold Lake	400	3	46.6ab	0.1a	0.43a	0.30c	0.30c	5.83a	435ab	134ab	126de	65.5ab	0.10a	8.07b	0.20a
Cold Lake	600	3	44.2bc	0.1a	0.43a	0.30c	0.30c	5.23a	435ab	136ab	180de	64.7b	0.10a	8.27b	0.20a
Cold Lake	800	3	41.7bc	0.1a	0.40a	0.30c	0.30c	4.50a	418b	134ab	241cd	63.5b	0.10a	8.83b	0.20a
Cold Lake	1200	3	38.5c	0.1a	0.50a	0.37bc	0.37bc	3.90a	415b	153a	378bc	74.3ab	0.10a	9.23b	0.20a
Cold Lake	1520	3	41.8bc	0.1a	0.53a	0.57a	0.57a	4.03a	418b	149a	422b	73.7ab	0.10a	9.53b	0.20a
Cold Lake	2400	3	44.4bc	0.1a	0.50a	0.50ab	0.50ab	5.53a	425ab	114b	629a	60.0b	0.10a	12.5a	0.20a
Slave Lake	0	3	152a	0.06a	0.60c	0.81c	2.81a	9.00bc	363a	78.5c	18.0c	69.8b	0.12b	11.7a	0.13a
Slave Lake	200	3	159a	0.05ab	0.63c	0.83a	2.43ab	6.72cd	360a	88.6bc	75.6bc	59.6bc	0.10b	12.5a	0.13a
Slave Lake	400	3	124a	0.04n	0.65c	0.79c	1.72cd	5.33d	349a	90.9bc	142bc	50.6c	0.10b	11.6a	0.13a
Slave Lake	600	3	113a	0.04b	0.67c	0.95c	1.48d	6.08d	323a	83.6c	183bc	53.6bc	0.11b	11.6a	0.13a
Slave Lake	800	3	119a	0.04b	0.87bc	1.06c	1.41d	6.99cd	328a	89.3bc	239abc	56.4bc	0.10b	11.6a	0.14a
Slave Lake	1200	3	134a	0.04b	1.14b	1.56b	1.67cd	9.58b	348a	109b	655ab	70.1b	0.10b	12.9a	0.13a
Slave Lake	2400	3	140a	0.05ab	1.64a	2.52a	2.02bc	17.1a	320a	143a	795a	91.0a	0.15a	13.8a	0.13a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Ni	Se
		(ug/g)	
Cold Lake	0	0.60a	0.8a
Cold Lake	200	0.47ab	0.8a
Cold Lake	400	0.20b	0.8a
Cold Lake	600	0.23b	0.8a
Cold Lake	800	0.20b	0.8a
Cold Lake	1200	0.20b	0.8a
Cold Lake	1520	0.33ab	0.8a
Cold Lake	2400	0.20b	0.8a
Slave Lake	0	0.38ab	0.75b
Slave Lake	200	0.32ab	0.75b
Slave Lake	400	0.24b	0.75b
Slave Lake	600	0.18b	0.75b
Slave Lake	800	0.24b	0.78b
Slave Lake	1200	0.37ab	0.75b
Slave Lake	2400	0.47a	1.17a

invert waste/soil mixtures from both sample locations showed significant changes in the DTPA extractable levels of Fe, Pb, Mn, Mg, Na, K, and Ni.

Significant changes in Pb, Zn, Mn, Ca, Na, and K occurred relative to the KCl waste/soil mixtures from the two sample locations. The NaCl waste/soil mixtures from both sample locations showed significant changes in Pb, Zn, Mg, Na, K, and Ni.

5.8 TOTAL ELEMENTAL CONTENT OF THE BROME GRASS

A comparison of the mean values for the total elemental content of the brome grass is presented in Tables 50 to 54.

For interpretation purposes the values from Tables 50 to 54 are compared to values reported in the literature (Chapman 1966) which represent a very wide range of plants. Values reported specifically for brome grass were available for two elements only. For the remaining elements the reported values represent a mean of values for "grasses" including bluegrass, ryegrass and timothy.

The data indicate that significant differences in the elemental content of the brome grass grown in all types of waste/soil mixtures occurred. Levels of specific elements such as Al, Cl, Zn, Mn, and Ca found in the tissue grown in the waste/soil mixtures were significantly different for all waste types from all regions.

Chloride levels generally increased with increasing application rate of all wastes from all locations. The lowest rate of waste applied resulted in increased Cl levels in the tissue for all wastes and sites, and in most cases the increase was statistically significant when compared to control values. The highest tissue chloride levels were associated with the invert, KCl and NaCl waste/soil mixtures.

Chloride values in Tables 50 to 54 range from 2660 μg/g to 24 700 μg/g. Chapman (1966) reports an intermediate range of 7000 ppm and a high range of 8700 to 15 400 ppm for chloride in grasses. Using these values as a guideline suggests that the application of invert, KCl and NaCl wastes resulted in high to very

Table 50. Comparison of the total elemental content (mean values) of the brome grass grown in the freshwater gel waste/soil mixtures.

Location	Cl Rate kg/ha	N	Al	Fe	Ti	Cr	V	Cu	Zn (ug/g)	Mn	Ca	Mg	Na	K	Li
Cold Lake	0	3	26.6a*	51.8a	6.7a	6.7a	6.7a	6.7a	20.7a	235a	6290a	2790ab	167d	27300a	6.7a
Cold Lake	20	3	42.3a	204a	6.7a	6.7a	6.7a	6.7a	10.2bc	67.1d	6780a	3190a	190d	30600a	6.7a
Cold Lake	40	3	26.5a	53.0a	6.7a	6.7a	6.7a	6.7a	8.84c	52.3d	6650a	3000ab	257d	28400a	6.7a
Cold Lake	80	3	35.8a	89.6a	6.7a	6.7a	6.7a	6.7a	11.8bc	73.7d	6270a	2840ab	268d	31500a	6.7a
Cold Lake	200	3	32.9a	103a	6.7a	6.7a	6.7a	6.7a	15.7abc	121bc	6080a	2680ab	446cd	31100a	6.7a
Cold Lake	400	3	17.6a	27.8a	6.7a	6.7a	6.7a	6.7a	13.9abc	130bc	5040ab	2110bc	681c	26900a	6.7a
Cold Lake	600	3	24.8a	89.2a	6.7a	6.7a	6.7a	6.7a	17.5abc	154b	5350ab	2190bc	1455b	31100a	6.7a
Cold Lake	800	3	24.1a	48.3a	6.7a	6.7a	6.7a	6.7a	16.9abc	166b	5100ab	2120bc	1830b	32900a	6.7a
Cold Lake	1200	3	14.7a	46.4a	6.7a	6.7a	6.7a	6.7a	13.8abc	97.8cd	4080b	1700c	2880a	31500a	6.7a
Rocky Mtn.	0	3	32.7ab	53.0a	0.85a	1.71a	2.56a	7.85b	17.0c	154a	3400a	1500a	81.2c	28100b	3.42a
Rocky Mtn.	17	3	38.0a	62.1a	0.85a	1.71a	2.56a	9.90b	24.3bc	189a	3810a	1200a	614c	36200ab	3.42a
Rocky Mtn.	25	3	19.1ab	58.1a	0.85a	2.00a	2.56a	12.0ab	39.2ab	177a	3300a	1620a	2510b	36900a	3.42a
Rocky Mtn.	51	3	17.1b	79.0a	0.85a	1.85a	2.56a	17.0a	55.1a	162a	2980a	2270a	8930a	37500a	3.42a
Waterton	0	3	19.7a	46.4a	0.85a	1.71a	2.56a	4.58b	25.4ab	54.0d	4700ab	2100ab	35.0e	27200bc	3.42a
Waterton	200	3	23.5a	38.3a	0.85a	1.71a	2.56a	5.72ab	28.9a	120bc	5120a	2440a	319de	35400ab	3.42a
Waterton	400	3	21.1a	56.3a	0.85a	1.71a	2.56a	6.29ab	26.9ab	184a	4420ab	2300ab	693cd	35200ab	3.42a
Waterton	600	3	19.0a	52.1a	0.85a	1.71a	2.56a	6.93ab	27.2ab	204a	3870bc	2170ab	1150c	37000a	3.42a
Waterton	800	3	20.4a	490a	0.85a	1.71a	2.56a	7.45a	24.3ab	188a	3250cd	1850b	1260bc	29700abc	3.42a
Waterton	1200	3	18.0a	32.1a	0.96a	1.71a	2.56a	6.34ab	19.8b	152ab	2140de	1090c	1760b	22800c	3.42a
Waterton	2400	3	17.1a	48.6a	0.85a	1.71a	2.56a	5.98ab	22.7ab	80.6cd	1570e	1020c	5890a	22700c	3.42a
G. Prairie	0	3	20.5a	68.1a	0.65a	1.80a	2.70a	5.78c	21.3c	171a	4130a	1540a	56.0e	34700a	3.60a
G. Prairie	65	3	13.9ab	68.2a	0.65a	1.80a	2.70a	7.14c	26.6bc	91.8b	3900a	1670a	475d	33200a	3.60a
G. Prairie	204	3	9.90b	73.2a	0.65a	1.80a	2.70a	9.60b	31.6ab	184a	3150b	1500a	1330c	36800a	3.60a
G. Prairie	408	3	9.90b	49.1a	0.65a	1.80a	2.70a	11.2b	34.8ab	157a	2770bc	1550a	3870b	35100a	3.60a
G. Prairie	612	3	9.90b	50.9a	0.65a	1.80a	2.70a	14.7a	39.5a	114b	2600c	1420a	5960a	34900a	3.60a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

continued...

Table 50. Continued.

Location	Cl Rate kg/ha	N	Sr	P	Ba	Mo	B	Ni	Se	S	Si	Co	As	Cd
									(ug/g)					
Cold Lake	0	3	13.3a*	1610a	48.7a	4.43a	19.2c	6.7a	20.1a	694b	691b	6.7a	23.6a	0.41ab
Cold Lake	20	3	14.6a	1400ab	39.4ab	10.5a	17.6c	6.7a	20.1a	1560a	589b	6.7a	23.3ab	0.45a
Cold Lake	40	3	13.3a	1420ab	33.1bc	4.42a	24.3bc	6.7a	20.1a	1620a	685b	6.7a	22.1abc	0.26ab
Cold Lake	80	3	13.3a	1460ab	25.0cd	4.26a	20.7c	6.7a	20.1a	1830a	925ab	6.7a	17.6abcd	0.20b
Cold Lake	200	3	12.8a	1330abc	18.5de	4.26a	24.2bc	6.7a	20.1a	1770a	955ab	6.7a	17.0abcd	0.20b
Cold Lake	400	3	10.9a	1040bc	13.2de	8.07a	32.1abc	6.7a	20.1a	1540a	1170a	6.7a	16.0abcd	0.20b
Cold Lake	600	3	13.1a	1190abc	13.1de	8.74a	49.5ab	6.7a	20.1a	1820a	1170a	6.7a	8.71bcd	0.20b
Cold Lake	800	3	14.1a	1150abc	14.1de	12.7a	52.2a	6.7a	20.1a	1940a	1100a	6.7a	5.60d	0.20b
Cold Lake	1200	3	13.8a	871c	8.87e	15.8a	39.1abc	6.7a	20.1a	2210a	1140a	6.7a	7.99cd	0.21b
Rocky Mtn.	0	3	14.7c	1690b	102a	4.25a	7.08a	2.56a	25.6a	2830b	725a	0.85a	18.5a	0.29a
Rocky Mtn.	17	3	22.8c	2020b	28.0b	4.25a	7.74a	2.56a	25.6a	4050ab	500a	0.85a	19.5a	0.52a
Rocky Mtn.	25	3	33.5b	2760ab	12.9bc	4.25a	7.40a	2.56a	25.6a	3870ab	399a	0.85a	24.5a	0.29a
Rocky Mtn.	51	3	72.0a	3200a	2.10c	4.33a	10.6a	2.56a	25.6a	5070a	643a	0.85a	24.1a	0.21a
Waterton	0	3	11.2c	1290a	22.1ab	4.25a	10.0a	2.56a	25.63a	2370a	576b	0.85a	17.2b	0.12a
Waterton	200	3	18.5ab	1160a	27.7a	4.25a	10.9a	2.56a	25.63a	2400a	543b	0.85a	25.5ab	0.50a
Waterton	400	3	19.5ab	1360a	19.8ab	4.25a	10.8a	2.56a	25.63a	2490a	456b	0.85a	27.2ab	0.29a
Waterton	600	3	20.7a	1380a	18.8ab	4.25a	13.4a	2.56a	25.63a	2470a	553b	0.85a	32.5a	0.10a
Waterton	800	3	19.6ab	1360a	15.0bc	4.25a	8.69a	2.56a	25.63a	2130ab	523b	0.85a	23.0ab	0.17a
Waterton	1200	3	14.2bc	1190a	7.00cd	4.25a	7.04a	2.56a	25.63a	1530b	1060a	0.85a	24.5ab	0.01a
Waterton	2400	3	16.8abc	1630a	2.21d	4.25a	10.8a	2.56a	25.63a	2530a	407b	0.85a	21.2b	0.04a
G. Prairie	0	3	13.5b	1370d	26.9a	4.50b	13.1a	2.70a	26.8a	1940d	548b	0.90a	32.6a	1.89a
G. Prairie	65	3	13.4b	1480d	8.64b	4.50b	9.32ab	2.70a	26.8a	2000d	570b	0.90a	28.4b	0.64a
G. Prairie	204	3	11.4c	2520c	4.50bc	4.50b	6.00b	2.70a	26.8a	2530c	774a	0.90a	26.3c	2.06a
G. Prairie	408	3	12.5bc	3260a	1.55c	4.50b	9.69ab	2.70a	26.8a	3160b	789a	0.90a	25.8c	0.73a
G. Prairie	612	3	17.1a	2870b	0.98c	9.20a	13.3a	2.70a	26.8a	3910a	720a	0.90a	25.4c	2.77a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

continued...

Table 50. Concluded.

Location	Cl Rate kg/ha	N	Pb	Cl
			—— (ug/g)	——
Cold Lake	0	3	0.31a*	2660d
Cold Lake	20	3	0.62a	3590cd
Cold Lake	40	3	0.22a	6060b
Cold Lake	80	3	0.20a	7100ab
Cold Lake	200	3	0.28a	9130a
Cold Lake	400	3	0.20a	6620b
Cold Lake	600	3	0.29a	6520b
Cold Lake	800	3	0.28a	5850bc
Cold Lake	1200	3	0.20a	5450bc
Rocky Mtn.	0	3	0.57a	4050b
Rocky Mtn.	17	3	0.58a	5540b
Rocky Mtn.	25	3	0.77a	8450ab
Rocky Mtn.	51	3	1.00a	11000a
Waterton	0	3	0.46a	5310b
Waterton	200	3	0.68a	8510ab
Waterton	400	3	0.50a	8780ab
Waterton	600	3	0.54a	11000a
Waterton	800	3	0.43a	12000a
Waterton	1200	3	0.50a	8510ab
Waterton	2400	3	0.04a	6300b
G. Prairie	0	3	2.97a	4940b
G. Prairie	65	3	0.34a	8720a
G. Prairie	204	3	0.29a	9360a
G. Prairie	408	3	0.43a	7560a
G. Prairie	612	3	0.64a	8260a

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* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Table 51. Comparison of the total elemental content (mean values) of the brome grass grown in the DAP waste/soil mixtures.

Location	Cl Rate	N	Al	Fe	Ti	Cr	V	Cu	Zn	Mn	Ca	Mg	Na	K	Li
	kg/ha								(ug/g)						
Cold Lake	0	3	25.2a*	44.3c	0.85a	1.71a	2.56a	4.65c	17.8b	99.0a	4760a	2320ab	47.5d	32000b	3.42c
Cold Lake	10	3	20.7ab	45.1c	0.85a	1.71a	2.56a	4.60c	20.4b	55.4b	4600a	2290ab	138d	32300b	3.42c
Cold Lake	124	3	22.6ab	65.8b	0.85a	1.71a	2.56a	11.0b	37.0a	88.5a	4670a	2600a	4550c	38400a	3.42c
Cold Lake	249	3	17.1b	86.7a	0.85a	1.71a	2.56a	13.5a	33.1a	61.6b	3450ab	1820b	9130b	29600b	4.70b
Cold Lake	373	3	17.1b	76.8ab	0.85a	1.71a	2.56a	13.4a	33.1a	57.2b	2910b	1630b	10500a	27300b	11.7a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate	Sr	P	Ba	Mo	B	Ni	Se	S	Si	Co	As	Cd	Pb	Cl
	kg/ha							(ug/g)							
Cold Lake	0	13.6b	2380c	34.8a	4.25c	10.7d	2.56a	25.6a	2310b	627a	0.85a	19.9b	0.25b	0.79a	4500d
Cold Lake	10	15.1b	2110c	30.6a	4.25c	16.2cd	2.56a	25.6a	2620b	534a	0.85a	34.3a	0.39b	0.43bc	5360cd
Cold Lake	124	31.8a	5090a	15.0b	4.25c	46.8b	2.56a	25.6a	3190b	573a	0.85a	28.4a	0.90a	0.72ab	8760a
Cold Lake	249	34.7a	4980a	6.84bc	10.3b	106a	2.56a	25.6a	4800a	547a	0.85a	19.9b	0.46b	0.41bc	6410bc
Cold Lake	373	34.7a	4170b	3.55c	14.0a	23.3c	2.56a	25.6a	4610a	482a	0.85a	19.7b	0.30b	0.34c	6940b

Table 52. Comparison of the total elemental content (mean values) of the brome grass grown in the invert waste/soil mixtures.

Location	Cl Rate kg/ha	N	Al	Fe	Ti	Cr	V	Cu	Zn	Mn	Ca	Mg	Na	K	Li
									(ug/g)						
Rocky Mtn.	0	3	32.7d*	53.0d	0.85b	1.71a	2.56a	7.85c	17.0b	154f	3400f	1500e	81.2d	28100cd	3.42a
Rocky Mtn.	200	3	41.1cd	72.5bc	0.85b	1.71a	2.56a	11.4a	25.7a	213e	4970e	2080cd	81.6d	37000ab	3.42a
Rocky Mtn.	400	3	31.9d	60.6cd	0.85b	1.71a	2.56a	10.1b	26.0a	228de	5270de	2020d	107d	36600ab	3.42a
Rocky Mtn.	600	3	46.7bc	79.9b	0.85b	1.71a	2.56a	11.4a	30.1a	301ab	7790c	2450ab	286c	38800a	3.42a
Rocky Mtn.	800	3	39.3cd	67.0bc	0.85b	1.71a	2.56a	9.88b	27.0a	253cd	6310d	2000d	124d	32800bc	3.42a
Rocky Mtn.	1200	3	53.7b	78.4b	0.85b	1.71a	2.56a	11.7a	30.9a	331a	11100b	2730a	402b	36000ab	3.42a
Rocky Mtn.	2400	3	97.4a	117a	0.97a	1.71a	2.56a	8.48c	26.3a	274bc	15000a	2370bc	717a	25800d	3.42a
G. Prairie	0	3	20.5d	68.1a	0.65a	1.80a	2.70a	5.78c	21.3d	171c	4130f	1540d	56.0e	34700a	3.60a
G. Prairie	200	3	30.6cd	82.8a	0.65a	1.80a	2.70a	7.91bc	30.1c	310b	6730e	2020c	99.7de	36500a	3.60a
G. Prairie	400	3	32.6c	78.5a	0.65a	1.80a	2.70a	8.73ab	33.7bc	338b	7710d	2110bc	127cd	35700a	3.60a
G. Prairie	600	3	48.5ab	91.3a	0.65a	1.80a	2.70a	10.7a	38.7ab	386a	10700b	2630a	214b	36400a	3.60a
G. Prairie	800	3	42.1bc	104a	0.65a	1.80a	2.70a	10.2a	41.9a	324b	9230c	2220bc	181bc	35100a	3.60a
G. Prairie	1200	3	55.6a	101a	0.65a	1.80a	2.70a	9.50ab	34.5bc	336b	12300a	2290b	526a	35100a	3.60a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Sr	P	Ba	Mo	B	Ni	Se	S	Si	Co	As	Cd	Pb	Cl
								(ug/g)							
Rocky Mtn.	0	14.7f	1690abc	102a	4.25a	7.08c	2.56a	25.6a	2830d	725a	0.85a	18.5ab	0.29a	0.57b	4050e
Rocky Mtn.	200	23.9e	1430bc	102a	4.25a	13.1ab	2.56a	25.6a	3230cd	728a	0.85a	17.5b	0.29a	0.33bcd	11600d
Rocky Mtn.	400	25.6e	1440bc	73.9b	4.25a	13.1ab	2.56a	25.6a	2820d	650a	0.85a	21.5ab	0.31a	0.22cd	12200d
Rocky Mtn.	600	36.7c	1560abc	57.6bc	4.25a	17.8a	2.56a	25.6a	3700bc	624a	0.85a	21.9ab	0.44a	0.18cd	13900c
Rocky Mtn.	800	31.3d	1350c	49.0cd	4.25a	10.2bc	2.56a	25.6a	3010d	814a	0.85a	21.3ab	0.28a	0.03d	12400cd
Rocky Mtn.	1200	55.5b	1820ab	45.1cd	4.25a	17.8a	2.56a	25.6a	4440a	641a	0.85a	22.4ab	0.52a	0.48bc	17000b
Rocky Mtn.	2400	79.3a	1850a	29.1d	4.25a	10.8bc	2.56a	25.6a	3840b	747a	0.85a	22.6a	0.32a	1.54a	24700a
G. Prairie	0	13.5f	1370d	26.9c	4.50a	13.1b	2.70a	26.8a	1940c	548b	0.90a	32.6a	1.90b	2.97a	4940d
G. Prairie	200	23.0e	1800c	44.2ab	4.50a	10.6b	2.70a	26.8a	2660b	621ab	0.90a	32.5a	1.37b	0.14b	10400c
G. Prairie	400	26.7d	2110bc	42.9ab	4.50a	11.4b	2.70a	26.8a	3000b	622ab	0.90a	31.9a	1.20b	2.54ab	10300c
G. Prairie	600	37.3b	2570a	46.5a	4.50a	22.7a	2.70a	26.8a	3780a	691a	0.90a	31.9a	0.92b	1.84ab	13100ab
G. Prairie	800	34.9c	2510ab	33.8bc	4.50a	13.8b	2.70a	26.8a	3600a	644ab	0.90a	31.5ab	5.88a	8.60a	13000b
G. Prairie	1200	42.8a	2560a	36.0abc	4.50a	19.3a	2.70a	26.8a	3740a	641ab	0.90a	30.6b	4.04ab	6.06ab	14670a

Table 53. Comparison of the total elemental content (mean values) of the brome grass grown in the KCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	Al	Fe	Ti	Cr	V	Cu	Zn	Mn	Ca	Mg	Na	K	Li
									(ug/g)						
Cold Lake	0	3	26.6ab*	51.8a	6.7a	6.7a	6.7a	6.7a	20.7ab	235a	6290d	2790a	167b	27300a	6.7a
Cold Lake	200	3	20.8b	35.7a	6.7a	6.7a	6.7a	6.7a	14.8b	140d	6040d	2390abc	119b	37200a	6.7a
Cold Lake	400	3	23.5b	39.2a	6.7a	6.7a	6.7a	6.7a	18.5b	142d	6900d	2550ab	120b	29100a	6.7a
Cold Lake	600	3	26.1b	37.8a	6.7a	6.7a	6.7a	6.7a	17.5b	156cd	7250cd	2520ab	136b	30400a	6.7a
Cold Lake	800	3	27.7ab	40.8a	6.7a	6.7a	6.7a	6.7a	20.4ab	175c	8310bc	2560ab	188b	31900a	6.7a
Cold Lake	1200	3	30.2ab	37.3a	6.7a	6.7a	6.7a	6.7a	18.7b	182bc	8710ab	2340bc	267b	28400a	6.7a
Cold Lake	2400	3	62.6a	88.4a	6.7a	6.7a	6.7a	6.7a	28.4a	208ab	9710a	2000c	1580a	36700a	6.7a
Waterton	0	3	19.7b	46.4b	0.85a	1.71a	2.56a	4.58a	25.4c	54.0c	4700d	2100a	35.0b	27200a	3.42a
Waterton	200	3	22.0ab	47.3ab	0.85a	1.71a	2.56a	4.23a	27.2c	84.0c	5170cd	2130a	39.1b	28600a	3.42a
Waterton	400	3	22.6ab	53.9ab	0.85a	1.71a	2.56a	4.11a	30.0bc	115bc	5180cd	2090a	62.1ab	29700a	3.42a
Waterton	600	3	24.7ab	45.8b	0.85a	1.71a	2.56a	3.35a	28.8bc	147bc	5360bcd	1970a	93.1ab	26700a	3.42a
Waterton	800	3	30.1ab	58.4ab	0.85a	1.71a	2.56a	4.71a	40.0abc	200ab	6720abc	2490a	150ab	33300a	3.42a
Waterton	1200	3	26.9ab	62.8ab	0.85a	1.71a	2.56a	5.00a	44.7ab	266a	7120ab	2490a	93.9ab	31900a	3.42a
Waterton	2400	3	32.2a	64.1a	0.85a	1.71a	2.56a	5.24a	48.3a	289a	8270a	2300a	231a	32900a	3.42a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cl Rate kg/ha	Sr	P	Ba	Mo	B	Ni	Se	S	Si	Co	As	Cd	Pb	Cl
									(ug/g)						
Cold Lake	0	13.3c	1610a	48.7a	4.43a	19.2a	6.7a	20.1a	694d	691a	6.7a	23.6a	0.41b	0.31b	2660c
Cold Lake	200	13.4c	1210bc	38.6ab	4.46a	11.9a	6.7a	20.1a	1270c	616ab	6.7a	13.4b	0.22b	0.20b	9970b
Cold Lake	400	16.9bc	1110bc	41.4ab	5.18a	13.3a	6.7a	20.1a	1460bc	537b	6.7a	15.5ab	0.20b	0.20b	10500b
Cold Lake	600	17.5bc	1050c	32.7abc	4.37a	13.1a	6.7a	20.1a	1540bc	532b	6.7a	11.0b	0.22b	0.20b	11500b
Cold Lake	800	20.4ab	1170bc	30.6bcd	4.67a	13.2a	6.7a	20.1a	1710b	545b	6.7a	11.7b	0.20b	0.20b	11100b
Cold Lake	1200	21.6ab	1050c	21.6cd	4.32a	16.1a	6.7a	20.1a	1670b	531b	6.7a	14.3ab	0.20b	0.23b	12600b
Cold Lake	2400	24.8a	1410ab	14.6d	5.76a	15.9a	6.7a	20.1a	2130a	559b	6.7a	16.0ab	1.22a	2.35a	22700a
Waterton	0	11.2c	1290a	22.1a	4.25a	10.0a	2.56a	25.6a	2370a	576a	0.85a	17.2a	0.12c	0.46a	5310c
Waterton	200	12.5bc	1160a	27.1a	4.25a	14.6a	2.56a	25.6a	2460a	493a	0.85a	23.4a	0.44ab	0.19a	8840b
Waterton	400	12.7bc	1110a	25.3a	4.25a	17.8a	2.56a	25.6a	2430a	521a	0.85a	23.7a	0.66a	0.09a	8090b
Waterton	600	13.2bc	970a	23.9a	4.25a	22.9a	2.56a	25.6a	2220a	462a	0.85a	23.3a	0.45ab	0.13a	8110b
Waterton	800	16.3bc	1200a	29.4a	4.25a	28.7a	2.56a	25.6a	2710a	499a	0.85a	20.8a	0.33bc	0.20a	10100b
Waterton	1200	18.1ab	1200a	31.0a	4.25a	12.9a	2.56a	25.6a	2740a	569a	0.85a	22.4a	0.36abc	0.20a	9360b
Waterton	2400	23.4a	1220a	25.1a	4.25a	13.6a	2.56a	25.6a	2650a	562a	0.85a	16.2a	0.59ab	0.51a	13400a

Table 54. Comparison of the total elemental content (mean values) of the brome grass grown in the NaCl waste/soil mixtures.

Location	Cl Rate kg/ha	N	Al	Fe	Ti	Cr	V	Cu	Zn	Mn	Ca	Mg	Na	K	Li
			(mg/L)												
Cold Lake	0	3	26.6ab*	51.8a	6.7a	6.7a	6.7a	6.7a	20.7a	235a	6290b	2790a	167a	27300a	6.7a
Cold Lake	200	3	19.6b	32.0a	6.7a	6.7a	6.7a	6.7a	14.5ab	182ab	5510b	2480a	150a	25000a	6.7a
Cold Lake	400	3	23.1ab	37.5a	6.7a	6.7a	6.7a	6.7a	14.4ab	170ab	6000b	2620a	192a	28600a	6.7a
Cold Lake	600	3	24.3ab	35.7a	6.7a	6.7a	6.7a	6.7a	12.9ab	162ab	6410b	2760a	259a	28300a	6.7a
Cold Lake	800	3	20.6b	35.5a	6.7a	6.7a	6.7a	6.7a	13.3ab	139b	6520b	2680a	195a	26700a	6.7a
Cold Lake	1200	3	31.7ab	54.8a	6.7a	6.7a	6.7a	6.7a	9.53b	135b	6800b	2620a	420a	27300a	6.7a
Cold Lake	1520	3	37.2a	42.9a	6.7a	6.7a	6.7a	6.7a	11.4ab	143b	7320ab	2660a	494a	27700a	6.7a
Cold Lake	2400	3	37.8a	63.3a	6.7a	6.7a	6.7a	6.7a	15.8ab	219ab	8920a	2800a	2238a	31900a	6.7a
Slave Lake	0	3	20.6b	42.5b	0.65a	1.80a	2.70a	6.05d	28.2c	165bc	4540d	1570d	84.0c	35500a	3.6a
Slave Lake	200	3	20.2b	43.7b	0.65a	1.80a	2.70a	6.57cd	32.8bc	192b	5030cd	1670cd	175c	33600a	3.6a
Slave Lake	400	3	24.1ab	63.8ab	0.65a	1.80a	2.70a	7.87cd	39.8abc	155c	5600bcd	1830bcd	260c	37600a	3.6a
Slave Lake	600	3	21.5b	60.9ab	0.65a	1.80a	2.70a	8.76bc	42.5ab	153c	5910bc	1950bcd	827bc	37800a	3.6a
Slave Lake	800	3	23.6b	69.5ab	0.65a	1.80a	2.70a	10.6b	42.9ab	173bc	6690b	2110b	914bc	39100a	3.6a
Slave Lake	1200	3	23.8ab	73.0ab	0.65a	1.80a	2.70a	10.9b	42.8ab	193b	6720b	2010bc	1430b	35700a	3.6a
Slave Lake	2400	3	30.9a	90.7a	0.65a	1.80a	2.70a	15.3a	50.2a	226a	8510a	2540a	3260a	37200a	3.6a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sr	P	Ba	Mo	B	Ni	Se	S	Si	Co	As	Cd	Pb	Cl
	(mg/L)													
Cold Lake	13.3a	1610ab	48.7a	4.43a	19.2a	6.7a	20.1a	694d	691ab	6.7a	23.6a	0.41ab	0.31a	2660c
Cold Lake	12.4a	1320bc	40.0ab	4.38a	13.0a	6.7a	20.1a	983cd	640ab	6.7a	13.9a	0.23b	0.23a	9750b
Cold Lake	11.5a	1370bc	38.9b	4.33a	12.9a	6.7a	20.1a	1260bc	748a	6.7a	14.4a	0.20b	0.20a	11400b
Cold Lake	12.9a	1310bc	34.4bc	4.30a	11.5a	6.7a	20.1a	1240bc	669ab	6.7a	17.4a	0.21b	0.31a	11700b
Cold Lake	13.3a	1280bc	31.1bc	4.44a	10.3a	6.7a	20.1a	1280bc	619ab	6.7a	16.3a	0.24b	0.20a	11700b
Cold Lake	13.2a	1200c	26.5c	4.41a	13.1a	6.7a	20.1a	1570b	612b	6.7a	15.4a	0.21b	0.20a	12300b
Cold Lake	12.9a	1270bc	25.7c	4.29a	14.2a	6.7a	20.1a	1700b	682ab	6.7a	14.3a	0.23b	0.20a	11900b
Cold Lake	15.9a	1820a	24.8c	6.07a	10.6a	6.7a	20.1a	2411a	645ab	6.7a	16.6a	0.81a	0.91a	18200a
Slave Lake	10.8e	1690b	22.9a	4.50a	17.8a	2.70a	26.8a	2030bc	622a	0.90a	32.5a	1.17a	7.65a	6320c
Slave Lake	11.3de	1560b	10.6b	4.50a	18.0a	2.70a	26.8a	1660c	565a	0.90a	32.7a	0.89a	1.48ab	1140ab
Slave Lake	12.9de	1700b	10.7b	4.50a	13.3ab	2.70a	26.8a	1970bc	507a	0.90a	32.7a	2.20a	3.49ab	11900ab
Slave Lake	14.5cd	1810b	10.0b	4.50a	10.6b	2.70a	26.8a	2330bc	419a	0.90a	33.2a	1.59a	0.00b	10100bc
Slave Lake	17.3bc	1960b	10.2b	4.50a	11.4ab	2.70a	26.8a	2680b	425a	0.90a	32.2a	4.52a	2.81ab	11160ab
Slave Lake	19.0b	2150b	8.14b	4.50a	12.9ab	2.70a	26.8a	2730ab	476a	0.90a	32.0a	2.68a	0.92ab	11200ab
Slave Lake	31.5a	3080a	8.70b	4.50a	15.2ab	2.70a	26.8a	3670a	502a	0.90a	32.1a	3.68a	2.76ab	14700a

high levels of chloride in the brome grass. It is difficult to assess the impact of high chloride levels on plant health and growth because the only consistent or general symptom of excess chloride is reduced leaf size and slower growth rate. However, for many plants sharply reduced growth occurs without leaf symptoms (Chapman 1966).

Calcium levels in the tissue generally increased with increasing application rate of invert, KCl and NaCl wastes. The calcium levels decreased with increasing application rates of freshwater gel and DAP wastes. Chapman (1966) reported a low range value of 6400 ppm and an intermediate range value of 10 400 to 17 500 ppm for ryegrass. Using these values as a guideline suggests that most of the calcium levels were in the low range for all waste application rates except for the higher concentrations of invert waste.

Sodium levels in the tissue increased with increasing application rate of the different wastes. Normal and excessive levels of sodium in grasses are 300 to 1100 ppm and 3200 to 43 700 ppm respectively. Using these criteria it was apparent that normal sodium levels were exceeded in the tissue grown in the DAP and the highest application rates of the freshwater gel waste/soil mixtures involving materials from the Rocky Mountain House, Waterton and Grande Prairie locations.

Relating tissue injury solely to sodium is difficult. There is a large amount of literature which indicates that the contribution of sodium to injury is confounded by levels of chloride or other elements (Chapman 1966).

The normal and excessive levels of sulphur in grasses are 2500, and 4500 to 7400 ppm respectively. Although there were significant differences in tissue sulphur pertinent to virtually all waste treatments from all locations, most of the values reported in Table 50 to 54 represent the "normal" range of sulphur.

Boron levels were generally higher in the brome grass tissue grown in the waste/soil treatment pots as compared to the tissue grown in the control soils. There were no significant differences in boron content of the tissue grown in the freshwater gel materials from the Rocky Mountain House and Waterton sites, the KCl wastes and the NaCl wastes from the Cold Lake area. The boron levels reported in Tables 50 to 54 are comparable to the intermediate range of 15 to 80 ppm B in grasses reported by Chapman (1966).

Zinc levels were generally higher in the waste/soil mixtures than the control soil with maximum levels occurring at the highest waste application rates. Although there were significant differences in zinc values for all waste treatments from all sites, the values reported in Tables 50 to 54 are comparable to the intermediate range of 14 to 48 ppm reported by Chapman (1966).

Copper levels in the brome grass tissue generally increased with increased application rate of all waste types. Levels of 1.0 to 5.1 ppm and 5.2 to 18.0 ppm copper are considered deficient and normal, respectively. Tissue grown in the Cold Lake and Waterton soils had copper levels that fit the upper portion of the deficient range whereas the tissue grown in the Rocky Mountain House and Grande Prairie soils had levels that fell into the lower portion of the normal range. Addition of waste improved the copper status of the soils and resulted in tissue copper values occurring in the normal range for grasses.

Potassium levels in the tissue did not exhibit any consistent increases or decreases relative to waste application rate. The values reported in Tables 50 to 54 are consistent with the normal range in grasses of 20 000 to 35 000 ppm (Chapman 1966).

For most of the waste/soil treatments tissue phosphorus status increased with increased waste application rate except for the KCl material. The deficient, normal and excessive phosphorus levels in tissue are 1800 to 2800 ppm, 2800, to 4400 and >5000 ppm, respectively (Chapman 1966).

The tissue obtained from brome grass grown in all of the pot soils demonstrated deficient levels of phosphorus. These levels were improved by the addition of most of the freshwater gel wastes and the DAP, invert and NaCl wastes.

There were no consistent trends in lead content of tissue for the different wastes and application rates thereof. The tissue lead values reported varied from 0.0 to 8.6, however, in general the values are close to the intermediate range mean values of 0.9 to 1.4 ppm lead in the edible portion of 13 crops (Chapman 1966).

6. SUMMARY

6.1 CHARACTERIZATION WORK

6.1.1 Liquid Phase Wastes

The 164 liquid phase samples representing five waste types were analysed for EC, pH and several anions and cations.

1. The invert liquid phase wastes were the least variable between locations while the freshwater gel wastes were the most variable between locations.
2. The pH values for most of the wastes were in the upper range of values that are encountered in most natural and soil waters.
3. The mean EC values ranged from a low of 0.6 dS/m in a freshwater gel waste to a high 32.0 dS/m in a NaCl waste.
4. The trace element contents of the liquid samples were generally low with many of the elements below the detection limit of the ICP-AES instrument.
5. The liquid phases of all wastes were generally unsuitable for drinking, aquatic life, irrigation and livestock watering because of the levels of various constituents.

6.1.2 Solid Phase Wastes

The solid phase samples were analysed for several chemical and physical properties, soluble ions in saturated paste extracts, plant available trace elements (DTPA extractable) and total elemental content.

6.1.2.1 Chemical and physical properties.

1. The mean pH values ranged from a low value of 7.93 in the Rocky Mountain House invert to a high value of 9.81 for the freshwater gel waste from the Cold Lake

location. Significant differences in mean pH values between sampling locations (regions) for a specific waste type occurred only for the invert waste.

2. Acid neutralizing capacity (ANC) mean values ranged from 3.16 to 24.7%. There were no significant differences in mean ANC values between locations (regions) for specific waste types.
3. Oil content was generally highest in the invert and KCl wastes with a maximum mean value of 7.69% for the invert waste from the Grande Prairie location.
4. The particle size distribution of the wastes varied widely. The freshwater gel wastes generally had the highest clay contents and the lowest sand contents of the major waste types characterized.

6.1.2.2 Saturated paste extract data.

1. With the exception of a few values for the freshwater gel samples the mean EC values, which ranged from 2.74 to 156 dS/m, render all wastes unsuitable as a plant growth medium.
2. Trace element levels in the wastes were quite low with a few exceptions and, for many of the elements were below the detection limits of the ICP instrument.

6.1.2.3 DTPA extractable elements.

1. The DTPA extractable element levels varied between waste type and between individual locations for a specific waste. None of the wastes contained consistently higher or lower levels of the individual elements.

6.1.2.4 Total elemental analysis.

1. The total element levels varied between waste type with none of the wastes containing consistently higher or lower levels of the individual elements.
2. Mean values for the various elements were within the range of values normally found in soils except for Na, K, Mg, Mo, and Zn.
3. The results suggest little hazard to plants and foraging animals from the potential uptake of trace elements.

6.1.2.5 Mineralogy.

1. Calcite ($CaCO_3$), quartz (SiO_2) and kaolinite were found in all of the wastes sampled.
2. Barite ($BaSO_4$), dolomite ($CaMg(CO_3)^2$), portlandite ($Ca(OH)_2$), illite, sylvite, and montmorillonite were also detected in some of the wastes.
3. The origin of the minerals such as barite, portlandite and most of the clays are likely due to addition from the drilling mud used initially. The calcite and dolomite are likely of geologic origin.

6.1.2.6 Oil separation characteristics.

1. Oil was extracted from the solid wastes by methylene chloride soxhlet extraction and extracted further into acid, base and neutral fractions.
2. Organic compounds were not evident in the acid or base fractions but concentrated in the neutral fraction. The largest fraction identified is comprised of saturated hydrocarbons with lesser amounts of PAH's.

6.1.3 Analysis of Sampling Design

6.1.3.1 Comparisons relative to depth and horizontal position.

6.1.3.1.1 Liquid phase wastes.

1. The horizontal position analysis indicated significant differences between the five positions for the analytical variables only for the NaCl waste from the Slave Lake area. This suggests that for the liquid phase in general, horizontal position or number of discrete sample locations, is insignificant.
2. Depth was more significant than horizontal position.

6.1.3.1.2 Solid phase wastes.

1. There was very little difference between depth and horizontal position for most of the physical and chemical parameters measured.
2. Comparison of means of saturated paste extract data showed no significant differences between depths for the invert waste whereas the other waste types exhibited some differences in the various parameters. Horizontal position means were different for a greater number of parameters and wastes than the depth means.
3. The only differences that occurred by depth for DTPA extractable elements involved the KCl waste from the Waterton site and NaCl waste from the Cold Lake site. Horizontal position means were different for a greater number of the waste types and individual parameters than depth means.
4. The only significant difference in total elemental analysis data that occurred by depth included Ca in the NaCl waste from the Slave Lake site. Horizontal position means were different for a number of parameters specific to each of the waste types.

5. Horizontal position was more significant than depth overall.

6.1.3.2 Number of samples required.

6.1.3.2.1 Liquid phase wastes.

1. The number of samples required to determine pH was relatively low ranging from one to ten depending upon waste type. The range was somewhat broader for the remaining parameters particularly some of the trace elements.

6.1.3.2.2 Solid phase wastes.

1. The number of samples required to characterize the solid phase wastes using physical and chemical properties, saturated paste extract data, DTPA extractable elements and total element data varied widely.
2. The lowest number of samples were required to determine pH and the highest number to determine extractable elements and soluble ions.
3. Most of the trace element levels could have been characterized with less than 20 samples and in many cases with less than ten samples at 20% accuracy.
4. Overall, the invert wastes required the lowest number of samples to complete the characterization relative to the parameters involved.

6.2 GREENHOUSE POT TRIALS

1. Three separate greenhouse experiments were conducted to coincide with the respective sampling and characterization activities. The rates of waste material added were based on chloride content and liming potential.

6.2.1 Plant Growth

1. Height growth was enhanced to some extent by the addition of all wastes except the invert to the respective soil materials.
2. For most of the wastes, the greatest mean height was achieved at the lowest waste application rate and height decreased as waste concentration added increased.

6.2.2 Yield

1. Significant reductions in yield from the control values occurred as invert waste application rate increased.
2. Comparisons regarding the freshwater gel waste/soil mixtures were somewhat difficult to make because of the variation in treatments (Cl rate) for the different regions. However, in most instances the lower application rates of all waste types enhanced yield which then decreased as waste concentration increased.

6.2.3 Chemical Properties of the Waste/Soil Mixtures

1. Significant increases in pH and $CaCO_3$ equivalent resulted from the addition of all waste types to the respective soils. Significant increases in carbon resulted from the addition of invert, DAP, KCl and some of the freshwater gel wastes.

6.2.4 Saturated Paste Extract Data for the Waste/Soil Mixtures

1. Statistically significant increases in EC, SAR, and Cl content occurred with increasing concentrations of all wastes from all locations.
2. The EC levels could be limiting to plant growth at some of the higher rates utilized for all wastes.

3. The SAR values suggested that potential limitations could occur with increasing concentration of freshwater gel, DAP and NaCl waste application.
4. Selecting 1000 ppm as the level at which chloride content begins to impact yield then rates in excess of 800 kg Cl/ha for the invert waste, and NaCl and KCl wastes from the Cold Lake area could be considered limiting because of chloride concentration in the resulting soil/waste medium.
5. The levels of cadmium, lead and selenium were not significantly altered by the addition of all waste types to soil. The levels of the remaining elements were significantly affected depending upon the specific waste and rate of application.

6.2.5 DTPA Extract Data for the Waste/Soil Mixtures

1. DTPA extractable element levels varied largely on the basis of waste type.

6.2.6 Total Elemental Content of Brome Grass

1. Significant differences in the elemental content of the brome grass grown in all types of waste/soil mixtures occurred.
2. Levels of specific elements including Al, Cl, Mn, Ca, and Zn in the waste/soil mixtures were significantly different for all waste types from all regions.
3. The highest tissue chloride levels were associated with the invert, KCl and NaCl waste/soil mixtures.
4. Tissue calcium levels generally increased with increasing application rate of invert, KCl and NaCl wastes and decreased with increasing application rates of freshwater gel and DAP wastes.
5. Normal tissue sodium levels were exceeded in the brome grass grown in the DAP waste/soil mixtures and at the

highest application rates of freshwater gel from some of the sampling locations.

6. Although there were significant differences in tissue sulphur pertinent to virtually all waste treatments from all locations most of the values reported represented the "normal" range for tissue sulphur.
7. Tissue boron and zinc levels were comparable to the respective intermediate range values reported by Chapman (1966).
8. Tissue copper levels generally increased with increased application rate for all waste types and no values exceeded the normal range. Addition of waste to the Cold Lake and Waterton soils increased tissue copper levels from the deficient to the normal range.
9. Deficient tissue phosphorus levels were detected in the brome grass grown in the different pot soils. These levels were improved by the addition of most of the waste types.

7. CONCLUSIONS

7.1 IMPACT OF WASTES ON SOILS

7.1.1 Positive Impacts

The lime content of the wastes can be considered as a positive characteristic particularly relative to acidic soils. The increase in $CaCO_3$ equivalent and pH resulting from waste addition is useful; however, application rates must be controlled to result in optimum levels for the parameters so that negative impacts such as micronutrient deficiencies do not occur. This is particularly true for the freshwater gel wastes when applied at the higher rates.

Although no work was done specifically to assess the impact of the waste on the physical characteristics of the greenhouse trial soils, it is possible that addition of some or all of the wastes could improve the "structure" and thereby properties such as water holding capacity of some soils. This type of investigation lends itself more to a field study rather than a laboratory or greenhouse experiment.

7.1.2 Negative Impacts

Assessment of the soil/waste mixture analytical data indicated that EC, SAR and pH values were the only measured factors that appeared potentially limiting to plant growth depending upon waste type and application rate.

The organic compounds present in the wastes are similar to those found in heavy oil fractions and weathered light oils. The largest fraction is made up of saturated hydrocarbons with lesser amounts of PAH's. The PAH's would pose the greatest challenge environmentally as they weather and degrade slowly. Application of this material to land could pose a hazard to groundwater quality due to the potential movement of water soluble and neutral compounds down the soil column.

7.2 IMPACT OF WASTES ON PLANTS

The observations presented herein are specific to brome grass, however, it is likely that the impacts could be similar for a number of crops and in particular other grass species.

7.2.1 Brome Grass Growth and Yield

Addition of invert wastes and KCl waste from the Waterton site resulted in overall growth and yield decreases from the control soil level as waste concentration increased. For the remaining wastes involved in this project, yield was enhanced at the lower waste application rates and then decreased with increased concentration. The enhancement in yield could be attributed to changes in the physical and chemical properties resulting from waste addition. The increase in pH, addition of nutrients and potentially improved physical characteristics of the pot soil could all be contributing to the increases in yield observed.

On the other hand decreases in yield could be attributed to an excess of waste material added. For example, at the higher application rates of freshwater gel, pH values become somewhat elevated and EC and SAR values in the soil could become a concern.

7.2.2 Total Elemental Content of Brome Grass

7.2.2.1 Positive impacts. Addition of all waste materials enhanced the copper and phosphorus status in the brome grass tissue. Tissue calcium levels were enhanced by the addition of the invert, KCl and NaCl wastes.

7.2.2.2 Negative impacts. Addition of KCl, NaCl and invert wastes resulted in tissue chloride levels in the defined "high range".

8. RECOMMENDATIONS

8.1 SAMPLING PROCEDURES

This section of the report describes some of the general procedures that should be employed to obtain appropriate samples for analysis. This discussion is based on the experience gained by the authors in completing this project. The outline provided cannot take into consideration all of the different site specific conditions that may be encountered by the sampler.

It must be recognized that the analytical work completed, and interpretation of results in characterization of a sump are only as good as the samples obtained; therefore care and caution must be exercised during the sampling process. The material below provides general information regarding sampling techniques.

8.1.1 Site History and Documentation

Background information regarding the contents of the sump sampled and a description of the location and sampling procedures utilized is important in the interpretation of the analytical results and development of disposal options. Documentation should include the following parameters.

1. Contents (type of waste(s)).
2. Dates for initiation and completion of disposal.
3. Date of sampling.
4. Legal location of sump site.
5. Sketch of sump denoting dimensions and sample site location.
6. Sample sites numbered or identified.
7. Type of containers and sampling apparatus used.
8. General comments regarding appearance of sump and material obtained, i.e., color, texture, odour, if any, and documentation of any problems that may have been encountered during the sampling procedure.

8.1.2 Components to Sample

The components to sample are dependent upon waste type and to some extent on ultimate disposal of the material; however, it is recommended that both the liquid and solid or semi-solid phases be sampled separately. The task is relatively simple when the phases are segregated in separate cells and becomes a bit more difficult when they are not segregated.

8.1.3 When to Sample

The time of sampling depends upon operational requirements and logistics, and the material to be sampled. A general recommendation is that the sampling event occur preferably no more than 30 days prior to disposal. In situations where a liquid layer overlays the solid materials, the sampling of solids should be undertaken after the liquids are drained or decanted. In other situations where the liquid phase overlays only portions of the entire sump area the solids can be sampled without any major problems.

8.1.3.1 Liquid materials. Winter sampling of liquid materials provides the advantages of the ice providing a stable setting or surface and no concerns regarding dilution by rainfall. The disadvantages include the fact that ice may concentrate toxicants, the site may be frozen to depth, and the difficulty in working with glass containers under freezing conditions.

Non-winter sampling offers the advantage that the entire depth can be sampled. The disadvantages include the fact that there may be more hazard involved and that samples can deteriorate more rapidly.

8.1.3.2 Solid or semi-solid materials. Winter sampling offers the advantages of a frozen or trafficable surface and less concern regarding sample deterioration. Disadvantages are associated with the depth and penetration of the frozen layer.

Non-winter sampling offers the advantage that the materials are easier to package and the disadvantage that many of the sumps are not trafficable.

8.1.4 How to Sample

How to sample includes consideration of equipment position or location, depth, volume required and preservation of samples obtained. These topics will be discussed separately relative to liquid and solid materials; however, some general recommendations applicable to both phases are presented.

Glass containers with a nonplastic lid should be used for samples that will be analysed for organics. Borosilicate glass is preferable for samples that will be subjected to the microtox test. Containers including new ones from a supplier should be rinsed with dilute 5% HNO_3 followed by distilled water prior to use. Plastic containers or bags used must be of the clear plastic type rather than coloured.

Samples should be obtained at least one metre from the margin of the sump to minimize the possibility of incorporating natural liner material in the sample or damaging synthetic liners.

8.1.4.1 Liquid wastes.

8.1.4.1.1 Equipment requirements. The equipment required for sampling liquid phase wastes could include some or all of the following items.

1. Boat or dinghy and safety equipment.
2. Ice auger for sampling frozen sites.
3. Discrete entity sampler or pump device.
4. Appropriate containers and safety equipment.

8.1.4.1.2 Sample site location and depth. The location from which samples are obtained, the different depths sampled, and the total number of samples acquired from a given sump are important considerations. The analytical results obtained in this study indicated that differences by depth were significant for some parameters and wastes, and generally insignificant relative to horizontal position. For the liquid materials, it could be recommended that compositing samples relative to horizontal position is acceptable and that discrete depth sampling be conducted. More specifically for sumps with a depth of less than 50 cm of liquid one sample from the midpoint in the depth column would be appropriate. For sumps in excess of 50 cm, one sample per 1 m of depth should be obtained in a manner that represents as much of the 1 m profile as possible.

For the purposes of this study samples were obtained from five locations with one to three discrete depth samples. It would be realistic, on the basis of the results achieved, to obtain depth interval samples from five locations and then composite relative to depth interval.

8.1.4.1.3 Sample volume. The volume required will be dependent on analyses to be conducted, however, it is prudent to collect more sample than required in the event that repeat analyses or loss of sample occur. Each liquid phase sample to be analysed should be at least 4 L in volume. Composite samples should be comprised of equal volumes of subsamples.

8.1.4.2 Solid wastes.

8.1.4.2.1 Equipment requirements. The equipment required for sampling solid phase wastes could include some or all of the following items.

1. Hand augers, shovels, spatulas.
2. Large equipment such as a backhoe for sumps that are not trafficable.
3. Appropriate containers including glass jars and plastic bags.

8.1.4.2.2 Sample site location and depth. For most of the sumps sampled in this study samples were obtained from three depth intervals at five locations or horizontal positions. The analytical results obtained indicated that differences by horizontal position were more significant than differences by depth for the various wastes and respective parameters. It is recommended that samples be obtained from a minimum of five locations in the sump and that samples be obtained on a depth basis.

For sumps having less than 50 cm of solid waste one sample from each position would be adequate. For sumps in excess of 50 cm in thickness one sample per 1 m of depth should be obtained in a manner that represents as much of the 1 m profile as possible. The samples should not be composited.

8.1.4.2.3 Sample volume. The volume required is dependent upon the analyses to be conducted and the moisture content at the time of sampling. The higher the moisture content the greater the volume of sample required. A 1-liter jar filled and relatively well packed along with approximately 2.5 kg of material in a plastic bag will be sufficient for appropriate analyses.

8.1.5 Sample Preservation

Preservation retards chemical and biological changes in the sample material collected. The major types of preservation that are employed include pH control, chemical addition, refrigeration and freezing. It is important to note that preservation precludes certain subsequent analyses. For example, the pH and conductivity of liquid materials should be determined in the field at the time of sampling. Subsequently, materials can be added to preserve the sample.

8.1.6 Sample Transport

When plastic bags are utilized double or triple bagging is appropriate to prevent punctures and ensure readability of the labels utilized. Small plastic pails with lids and lined with clear plastic can be used instead of plastic bags.

Depending upon waste type and mode of transport or shipping, Dangerous Goods Act labels may be required. The samples should be kept at 4°C or lower and delivered to the laboratory as soon as possible.

8.1.7 Sample Storage

Rapid freezing can be used to preserve samples. Samples should be refrigerated if possible, otherwise samples stored at temperatures greater than 4°C in excess of 48 hours could be considered questionable.

8.1.8 Safety Issues

Safety is the prime consideration when planning and executing a waste sampling program. The following points address some of the major factors that must be considered.

1. Know what is being sampled - what are the hazards?
2. Make certain the area is safe, i.e., H_2S detection etc.
3. Never work alone.
4. Use appropriate clothing - gloves, safety glasses, coveralls, special suits, proper footwear.

8.2 LANDSPREADING OF SOLID WASTES

The current guidelines or requirements for the disposal of drilling wastes on land are outlined in Interim Directive No. ID-OG 75-2 (ERCB 1975). The criteria involve sump volume, chloride content, sulphate content, total dissolved solids, pH and the trout test.

8.2.1 Criteria for Landspreading

It is apparent from the data obtained from the greenhouse studies in this project that pH, EC, SAR and Cl values tend to be the most limiting properties relative to the impact of waste application on the suitability of waste/soil mixtures for plant growth. Oil content should also be included. However, more work would be required to separate the impact of oil from that of salts contained in invert wastes in terms of specifically assessing the impact of oil.

The use of chloride addition as the criteria for determining KCl, NaCl and invert waste application rates appears to be appropriate. Liming potential in conjunction with chloride content would likely be a more appropriate criterion for determination of application rates for the DAP and freshwater gel wastes.

8.2.2 Calculation of Application Rates

Depending upon the criteria selected for the application of drilling wastes, potential rates that might be applied could be based partially on the criteria of the Alberta Soils Advisory Committee (1977, 1987). These criteria provide limits for various parameters relative to occurrence of no, slight, moderate and severe limitations in regard to soil properties as they affect plant growth or crop production. It should be noted that trace element levels are not included in the above mentioned criteria.

Matching the various parameters associated with the waste/soil mixtures following waste application with the criteria established provides an indication of the degree of limitation that might be expected.

8.3 RESEARCH REQUIRED

The results of this project provide a significant amount of insight into the characteristics of different drilling wastes and the potential impact of these wastes on soils and plants; however, some work still remains.

1. Field trials should be undertaken to verify the initial results obtained from the greenhouse component

of this study regarding the impact of waste addition to soils. Some of this work pertinent to freshwater gel, KCl and NaCl wastes is currently being investigated jointly by the Alberta Research Council and Esso Resources Canada Ltd. Invert waste is currently being studied in a field experiment by Environment Canada and the Canadian Petroleum Association (Ashworth et al. 1989).

2. Further work is needed to determine the cause(s) of impact to soils and plants resulting from the landspreading of invert wastes. Is it the oil content or the salt(s) present in the waste or a combination of the two that results in the impacts observed?

9. REFERENCES

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10. APPENDICES

10.1 COMPARISON OF THE MEAN VALUES BY DEPTH OF THE CHEMICAL PROPERTIES OF THE LIQUID PHASE SAMPLES

Comparison of the mean values by depth of the chemical properties of the freshwater gel waste liquid phase samples.

Location	N	Depth (cm)	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd
										(mg/L)					
Cold Lake	5	0–15	8.36a*	0.669a	312a	305a	6.90a	0.12a	91.1a	0.38a	0.1a	0.84a	0.1a	0.10a	0.1a
Cold Lake	5	15–75	8.35a	0.671a	316a	309a	6.57a	0.11a	88.4a	0.48a	0.1a	0.96a	0.1a	0.20b	0.1a
Cold Lake	4	75–120	8.37a	0.679a	303a	297a	6.66a	0.11a	91.2a	0.28a	0.1a	0.93a	0.1a	0.13a	0.1a
Waterton	5	0–15	8.42a	2.25a	506a	493a	13.01a	0.14a	509a	0.20a	0.14a	1.09a	0.03a	0.01a	0.01a
Waterton	5	15–50	8.26a	2.70a	616a	600a	16.1a	0.13a	391a	2.85a	0.49a	1.82a	0.04a	0.02a	0.01a
Waterton	5	50–100	8.90a	3.12a	663a	579a	83.5a	0.76a	364a	13.5a	0.55a	5.57a	0.05a	0.09a	0.01a
G. Prairie1	5	0–25	7.64b	0.73a	94.9ab	94.4a	0.44a	0.02a	56.7b	0.35a	0.06a	0.35a	0.03a	0.01a	0.01a
G. Prairie1	5	25–50	7.62b	0.73a	83.7b	83.4a	0.34a	0.02a	58.3b	0.30a	0.06a	0.30a	0.03a	0.01a	0.01a
G. Prairie1	5	50–100	8.94a	3.85a	229a	190a	37.0a	1.22a	244a	1.54a	0.29a	0.55a	0.03a	0.03a	0.01a
G. Prairie2	5	0–25	6.84b	0.24c	64.8b	64.7b	0.06b	0.00b	6.25c	6.91b	0.02b	1.97b	0.03b	0.06b	0.01a
G. Prairie2	5	25–75	9.72a	0.59b	282b	177a	102b	2.85b	20.2b	171a	0.14a	45.3a	0.34a	1.35a	0.01a
G. Prairie2	5	75–125	10.1a	0.97a	528a	225a	296a	9.61a	32.4a	214a	0.17a	56.3a	0.42a	1.68a	0.01a
G. Prairie3	5	0–25	7.94a	0.79a	181b	180b	1.50a	0.04a	135a	0.41a	0.02a	0.22a	0.03a	0.02a	0.01a
G. Prairie3	5	25–75	7.76a	0.84a	188b	187b	1.06a	0.03a	144a	0.28a	0.02a	0.21a	0.03a	0.02a	0.01a
G. Prairie3	5	75–140	8.42a	1.54a	308a	294a	13.5a	0.22a	301a	2.64a	0.07a	0.89a	0.03a	0.05a	0.01a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Depth (cm)	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni
								(mg/L)								
Cold Lake	0–15	0.1a	0.1a	0.1a	0.1a	15.8a	4.4a	242a	0.5a	0.1a	0.10a	0.1a	0.40a	0.1a	0.1a	0.1a
Cold Lake	15–75	0.1a	0.1a	0.1a	0.1a	17.6a	5.5a	245a	1.1a	0.1a	0.10a	0.1a	0.40a	0.1a	0.1a	0.1a
Cold Lake	75–120	0.1a	0.1a	0.1a	0.1a	17.2a	5.1a	248a	7.2a	0.1a	0.10a	0.1a	0.40a	0.1a	0.1a	0.1a
Waterton	0–15	0.01a	0.1a	0.07a	0.44a	82.8a	25.5a	659a	32.8a	0.04a	1.55a	0.30a	0.25a	0.13a	0.15a	0.03a
Waterton	15–50	0.01a	0.1a	0.08a	0.21a	46.7a	13.3a	744a	28.9a	0.04a	1.01a	0.18a	0.19a	0.26a	0.35a	0.03a
Waterton	50–100	0.01a	0.1a	0.10a	0.19a	33.2a	10.0a	777a	30.0a	0.04a	0.82a	0.20a	0.21a	0.32a	0.14a	0.03a
G. Prairie1	0–25	0.01a	0.10a	0.20a	0.01a	21.1a	3.45a	141a	1.82b	0.04a	0.14a	0.07a	0.04b	0.10b	0.05a	0.03a
G. Prairie1	25–75	0.02a	0.10a	0.20a	0.01a	20.9a	3.45a	142a	1.80b	0.04a	0.14a	0.07a	0.04b	0.10b	0.05a	0.03a
G. Prairie1	75–125	0.02a	0.10a	0.13a	0.02a	40.0a	4.51a	1120a	9.95a	0.04a	0.81a	0.20a	0.16a	0.22a	0.22a	0.03a
G. Prairie2	0–25	0.03a	0.10b	0.03b	0.01b	6.72b	2.19b	46.7c	2.73b	0.04a	0.05b	0.05b	0.06b	0.43b	0.05b	0.03b
G. Prairie2	25–75	0.04a	0.59a	0.20a	0.15a	14.0ab	24.3a	167b	26.6a	0.06a	0.20a	1.18a	0.47a	14.1a	0.12ab	0.05ab
G. Prairie2	75–125	0.04a	0.76a	0.26a	0.18a	14.8a	30.4a	253a	33.5a	0.07a	0.27a	1.56a	0.65a	20.1a	0.15a	0.06a
G. Prairie3	0–25	0.02a	0.10a	0.02a	0.03a	36.1a	16.1a	137b	3.23a	0.04a	0.22a	0.07b	0.07a	0.10a	0.06a	0.03a
G. Prairie3	25–75	0.02a	0.10a	0.02a	0.05a	35.1ab	16.1a	148b	2.54a	0.04a	0.22a	0.07b	0.07a	0.10a	0.06a	0.03a
G. Prairie3	75–140	0.01a	0.10a	0.05a	0.04a	18.1b	7.16b	361a	4.60a	0.04a	0.23a	0.14a	0.06a	0.25a	0.09a	0.03a

Concluded. Comparison of the mean values by depth of the chemical properties of the freshwater gel waste liquid phase samples.

Location	N	Depth (cm)	Se	Co	S	Si	As
					(mg/L)		
Cold Lake	5	0–15	0.1a*	0.1a	39.9a	8.66a	0.2a
Cold Lake	5	15–75	0.1a	0.1a	40.4a	8.26a	0.2a
Cold Lake	4	75–120	0.1a	0.1a	41.0a	8.15a	0.2a
Waterton	5	0–15	0.30a	0.01a	178a	8.90a	0.40a
Waterton	5	15–50	0.30a	0.01a	207a	18.0a	0.46a
Waterton	5	50–100	0.30a	0.01a	216a	41.7a	0.50a
G. Prairie1	5	0–25	0.30a	0.01a	70.8a	3.56a	0.03a
G. Prairie1	5	25–50	0.30a	0.01a	70.8a	3.36a	0.03a
G. Prairie1	5	50–100	0.30a	0.01a	612a	6.57a	0.16a
G. Prairie2	5	0–25	0.30b	0.01a	11.4b	15.3b	0.11c
G. Prairie2	5	25–75	0.79ab	0.02a	24.8b	384a	0.28b
G. Prairie2	5	75–125	0.97a	0.02a	41.7a	492a	0.40a
G. Prairie3	5	0–25	0.30a	0.02a	19.2b	5.14a	0.15a
G. Prairie3	5	25–75	0.30a	0.02a	20.6b	4.89a	0.15a
G. Prairie3	5	75–140	0.30a	0.01a	38.7a	10.4a	0.24a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by depth of the chemical properties of the invert waste liquid phase samples.

Location	N	Depth (cm)	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu
					(mg/L)											
Rocky Mtn.	5	0–15	7.60a*	3.25a	305a	304a	1.37a	0.03a	1270a	1.29a	0.02a	0.01a	0.03a	0.01a	0.01a	0.05a
Rocky Mtn.	5	15–30	8.66a	4.19a	223a	192a	29.20a	1.92a	2590a	3.76a	0.02a	0.01a	0.03a	0.02a	0.01a	0.11a
G. Prairie	5	0–25	6.88b	1.91b	290a	290a	0.25a	0.00a	435b	1.08a	0.02a	0.13a	0.03a	0.01a	0.01a	0.01a
G. Prairie	5	25–75	7.36ab	2.72a	233b	232b	0.50a	0.01a	808a	1.37a	0.02a	0.04b	0.03a	0.03a	0.01a	0.01a
G. Prairie	5	75–150	7.54a	3.01a	226b	225b	0.87a	0.02a	919a	1.48a	0.02a	0.05b	0.03a	0.02a	0.01a	0.01a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se
	(mg/L)														
Rocky Mtn.	0.1a	0.08a	0.07a	385a	17.70a	553a	32.70a	0.30a	5.63a	0.16a	0.72a	0.10a	0.05a	0.03a	0.03a
Rocky Mtn.	0.1a	0.13a	0.05a	957a	20.30a	672a	60.80a	0.36a	14.30a	0.51a	0.63a	0.14a	0.05a	0.04a	0.03a
G. Prairie	0.10a	0.08a	0.17a	278b	24.7a	294a	10.2a	0.11a	1.16a	0.17b	0.15a	0.73a	0.05a	0.04a	0.03a
G. Prairie	0.10a	0.02a	0.10a	384ab	18.6a	312a	9.03a	0.06a	0.73a	0.23ab	0.14a	0.10a	0.05a	0.03a	0.03a
G. Prairie	0.10a	0.02a	0.13a	456a	18.9a	331a	9.76a	0.06a	0.82a	0.27a	0.14a	0.10a	0.05a	0.03a	0.03a

Location	Co	S	Si	As
	(mg/L)			
Rocky Mtn.	0.01a	33.6a	6.91a	0.23a
Rocky Mtn.	0.01a	40.4a	7.34a	0.14a
G. Prairie	0.01a	82.9a	14.7a	0.19a
G. Prairie	0.01a	72.2a	8.52a	0.14b
G. Prairie	0.01a	73.6a	8.60a	0.13b

Comparison of the mean values by depth of the chemical properties of the KCl waste liquid phase samples.

Location	N	Depth (cm)	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu
					(mg/L)											
Cold Lake	5	0–15	8.19a*	10.0a	107a	106a	1.57a	0.08a	4930a	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Cold Lake	5	15–75	8.24a	10.0a	111a	109a	1.55a	0.09a	4940a	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Cold Lake	5	75–120	8.19a	9.99a	108a	106a	1.82a	0.08a	4930a	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Waterton	5	0–25	7.56a	23.8a	289a	288a	0.99a	0.02a	9160a	3.23a	0.02a	1.85a	0.03a	0.01a	0.01a	0.01a
Waterton	5	25–75	7.60q	23.9a	292a	291a	1.11a	0.02a	9110a	2.62a	0.02a	1.43a	0.03a	0.01a	0.01a	0.01a
Waterton	5	75–140	8.48q	25.4a	293a	276a	16.8a	0.43a	9450a	2.75a	0.02a	0.44b	0.03a	0.01a	0.01a	0.01a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Co	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se
	(mg/L)															
Cold Lake	0.1a	0.1a	0.1a	0.1a	76.7a	21.3a	2230a	2000a	0.3a	1.92a	0.4a	4.64a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	0.1a	74.9a	21.0a	2170a	1930a	0.3a	1.90a	0.4a	4.57a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	0.1a	74.4a	20.8a	2210a	1920a	0.3a	1.90a	0.4a	4.52a	0.1a	0.1a	0.1a	0.1a
Waterton	0.01a	0.1a	0.18a	2.22a	668a	136a	1910a	6530a	0.33a	11.9a	0.09ab	0.42a	0.30a	0.05a	0.03a	0.30a
Waterton	0.01a	0.1a	0.19a	2.21a	665a	136a	1910a	6570a	0.33a	11.8a	0.12a	0.42a	0.32a	0.05a	0.03a	0.30a
Waterton	0.01a	0.1a	0.18a	0.90b	708a	118a	1970a	6740a	0.34a	12.3a	0.04b	0.32a	0.33a	0.06a	0.03a	0.30a

Location	S	Si	As
	(mg/L)		
Cold Lake	79.7a	3.92a	0.1a
Cold Lake	77.8a	3.78a	0.1a
Cold Lake	77.0a	3.84a	0.1a
Waterton	455a	5.82a	0.10a
Waterton	453a	7.00a	0.09a
Waterton	461a	7.92a	0.07a

Comparison of the mean values by depth of the chemical properties of the NaCl waste liquid phase samples.

Location	N	Depth (cm)	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu
					(mg/L)											
Cold Lake	5	0–15	8.98b*	21.4a	275a	252a	22.9b	224a	12000b	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Cold Lake	5	15–75	9.12b	20.8a	281a	247a	33.3b	0.75b	11900b	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Cold Lake	5	75–120	11.5a	54.0a	690a	13.9b	452a	0.50b	31700a	0.10a	0.1a	0.10a	0.1a	0.10a	0.1a	0.1a
Slave Lake	5	0–25	7.59a	1.31a	39.5a	39.0a	0.49b	0.05b	366a	0.46a	0.02a	0.32a	0.03a	0.01a	0.01a	0.02a
Slave Lake	4	25–75	7.88a	1.47a	49.9a	48.9a	0.92b	0.08b	410a	0.37a	0.02a	0.24a	0.03a	0.01a	0.01a	0.02a
Slave Lake	2	75–90	9.10a	1.93a	81.9a	72.1a	9.11a	0.65a	538a	0.34a	0.02a	0.01a	0.03a	0.01a	0.01a	0.02a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Co	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se
	(mg/L)															
Cold Lake	0.1a	0.1a	0.1a	0.1a	31.2a	7.3a	8100b	122ab	0.1a	0.92a	0.2a	0.18a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	0.1a	28.3a	6.9a	8100b	105b	0.1a	0.88a	0.1a	0.18a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	0.1a	133b	0.7b	19600a	251a	0.1a	2.56a	0.1a	0.10a	0.1a	0.1a	0.1a	0.1a
Slave Lake	0.01a	0.10a	0.04a	0.12a	42.4a	8.59a	230a	7.08a	0.04a	0.31b	0.10a	0.05a	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.01a	0.10a	0.05a	0.09a	40.1a	7.78a	263a	8.11a	0.04a	0.32b	0.09a	0.05a	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.01a	0.10a	0.05a	0.01a	43.9a	6.58a	354a	11.3a	0.04a	0.49a	0.09a	0.06a	0.10a	0.05a	0.03a	0.30a

Location	S	Si	As
	(mg/L)		
Cold Lake	90.6ab	6.9a	0.1a
Cold Lake	72.7b	6.9a	0.1a
Cold Lake	206a	6.4b	0.1a
Slave Lake	21.9a	2.66a	0.03a
Slave Lake	21.6a	2.15a	0.04a
Slave Lake	21.5a	1.55a	0.04a

10.2 COMPARISON OF THE MEAN VALUES BY HORIZONTAL POSITION OF THE CHEMICAL PROPERTIES OF THE LIQUID PHASE SAMPLES

Comparison of the mean values by horizontal position of the chemical properties of the freshwater gel liquid phase samples.

Location	N	Hole No.	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu
					(mg/L)											
Cold Lake	2	4	8.24a*	0.667a	317a	312a	5.10a	0.09a	84.5a	0.50a	0.1a	0.85a	0.1a	0.15a	0.1a	0.1a
Cold Lake	3	5	8.41a	0.672a	298a	290a	7.05a	0.13a	96.1a	0.47a	0.1a	0.97a	0.1a	0.17a	0.1a	0.1a
Cold Lake	3	6	8.33a	0.673a	313a	306a	6.47a	0.11a	87.2a	0.50a	0.1a	0.83a	0.1a	0.13a	0.1a	0.1a
Cold Lake	3	7	8.36a	0.674a	314a	607a	6.67a	0.12a	87.3a	0.27a	0.1a	0.93a	0.1a	0.13a	0.1a	0.1a
Cold Lake	3	8	8.43a	0.677a	314a	306a	7.73a	0.13a	98.3a	0.23a	0.1a	0.93a	0.1a	0.13a	0.1a	0.1a
Waterton	3	1	8.23a	2.31a	503a	490a	12.4a	0.13a	492a	0.20a	0.15a	0.89a	0.03a	0.01a	0.01a	0.01a
Waterton	3	2	8.37a	2.18a	514a	501a	12.7a	0.14a	480a	0.20a	0.16a	0.85a	0.03a	0.01a	0.01a	0.01a
Waterton	3	3	8.43a	2.41a	619a	597a	21.9a	0.18a	420a	2.35a	0.32a	1.53a	0.03a	0.02a	0.01a	0.01a
Waterton	3	4	8.77a	3.42a	720a	636a	83.7a	0.63a	350a	8.65a	0.69a	4.07a	0.05a	0.05a	0.01a	0.01a
Waterton	3	5	8.83a	3.13a	618a	561a	57.1a	0.63a	366a	16.2a	0.65a	6.80a	0.06a	0.11a	0.01a	0.01a
G. Prairie1	3	1	8.00a	4.23a	166a	152a	13.7a	0.27a	105a	0.49a	0.13a	0.31a	0.03a	0.01a	0.01a	0.02a
G. Prairie1	3	2	8.30a	1.30a	109a	100a	8.60a	0.35a	129a	0.71a	0.10a	0.36a	0.03a	0.01a	0.01a	0.02a
G. Prairie1	3	3	7.93a	1.35a	170a	163a	6.58a	0.12a	129a	0.61a	0.26a	0.40a	0.03a	0.03a	0.01a	0.01a
G. Prairie1	3	4	8.40a	1.23a	138a	103a	33.6a	1.34a	179a	1.50a	0.12a	0.61a	0.03a	0.02a	0.01a	0.01a
G. Prairie1	3	5	7.70a	0.74a	95.8a	95.2a	0.50a	0.03a	56.4a	0.34a	0.06a	0.33a	0.03a	0.01a	0.01a	0.01a
G. Prairie2	3	1	8.77a	0.54a	262a	150a	110a	2.76a	17.4a	155a	0.12a	37.5a	0.29a	1.19a	0.01a	0.03a
G. Prairie2	3	2	8.90a	0.48a	193a	133a	58.2a	1.85a	15.0a	94.6a	0.09a	26.3a	0.21a	0.76a	0.01a	0.04a
G. Prairie2	3	3	8.90a	0.64a	318a	162a	153a	3.69a	21.5a	97.8a	0.08a	26.8a	0.21a	0.79a	0.01a	0.03a
G. Prairie2	3	4	9.10a	0.74a	413a	193a	216a	4.31a	24.5a	167a	0.14a	44.6a	0.35a	1.33a	0.01a	0.03a
G. Prairie2	3	5	8.80a	0.60a	272a	141a	127a	3.48a	19.6a	139a	0.11a	37.4a	0.26a	1.10a	0.01a	0.04a
G. Prairie3	3	1	7.80a	0.85a	194a	193a	1.25a	0.03a	147a	0.49a	0.02a	0.24a	0.03a	0.02a	0.01a	0.02a
G. Prairie3	3	2	7.80a	0.84a	201a	199a	1.22a	0.03a	160a	0.28a	0.02a	0.18a	0.03a	0.02a	0.01a	0.02a
G. Prairie3	3	3	8.17a	1.19a	235a	229a	6.01a	0.11a	217a	0.42a	0.04a	0.20a	0.03a	0.02a	0.01a	0.02a
G. Prairie3	3	4	8.10a	1.12a	257a	250a	6.80a	0.11a	186a	3.37a	0.05a	1.23a	0.03a	0.06a	0.01a	0.02a
G. Prairie3	3	5	8.33a	1.30a	241a	229a	11.4a	0.20a	256a	0.98a	0.05a	0.36a	0.03a	0.03a	0.01a	0.02a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg $CaCO_3$/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Continued. Comparison of the mean values by horizontal position of the chemical properties of the freshwater gel liquid phase samples.

Location	N	Hole No.	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo
									(mg/L)						
Cold Lake	2	4	0.1a*	0.1a	0.1a	19.7a	6.8a	244a	2.1a	0.1a	0.1a	0.1a	0.4a	0.1a	0.1a
Cold Lake	3	5	0.1a	0.1a	0.1a	17.0a	5.1a	243a	0.6a	0.1a	0.1a	0.1a	0.4a	0.1a	0.1a
Cold Lake	3	6	0.1a	0.1a	0.1a	16.2a	4.8a	243a	9.8a	0.1a	0.1a	0.1a	0.4a	0.1a	0.1a
Cold Lake	3	7	0.1a	0.1a	0.1a	15.9a	4.3a	244a	0.2a	0.1a	0.1a	0.1a	0.4a	0.1a	0.1a
Cold Lake	3	8	0.1a	0.1a	0.1a	16.3a	4.5a	248a	0.2a	0.1a	0.1a	0.1a	0.4a	0.1a	0.1a
Waterton	3	1	0.10a	0.06a	0.38a	74.9a	22.3a	637a	33.0a	0.04a	1.51a	0.30a	0.24a	0.12a	0.05a
Waterton	3	2	0.10a	0.07a	0.38a	71.9a	22.0a	636a	30.2a	0.04a	1.44a	0.28a	0.24a	0.13a	0.23a
Waterton	3	3	0.10a	0.08a	0.24a	53.5a	15.5a	696a	32.8a	0.04a	1.05a	0.19a	0.20a	0.27a	0.24a
Waterton	3	4	0.10a	0.11a	0.23a	37.4a	11.4a	841a	27.5a	0.04a	0.84a	0.14a	0.18a	0.30a	0.38a
Waterton	3	5	0.10a	0.11a	0.17a	33.5a	11.7a	825a	29.5a	0.04a	0.78a	0.20a	0.22a	0.37a	0.16a
G. Prairie1	3	1	0.10a	0.14a	0.02a	39.2a	5.56a	1240a	7.16a	0.04a	0.80a	0.06a	0.11a	0.15a	0.19a
G. Prairie1	3	2	0.10a	0.04a	0.01a	30.8a	3.55a	301a	3.94a	0.04a	0.31a	0.10a	0.07a	0.16a	0.18a
G. Prairie1	3	3	0.10a	0.05a	0.01a	24.6a	3.60a	389a	4.33a	0.04a	0.29a	0.13a	0.07a	0.14a	0.13a
G. Prairie1	3	4	0.10a	0.04a	0.01a	21.4a	2.84a	273a	5.38a	0.04a	0.27a	0.21a	0.11a	0.14a	0.09a
G. Prairie1	3	5	0.10a	0.02a	0.01a	20.7a	3.47a	140a	1.81a	0.04a	0.13a	0.07a	0.04a	0.10a	0.05a
G. Prairie2	3	1	0.58a	0.17a	0.13a	13.3a	22.0a	150a	23.7a	0.06a	0.20a	1.09a	0.39a	11.0a	0.11a
G. Prairie2	3	2	0.37a	0.13a	0.08a	10.2a	14.0a	124a	16.0a	0.05a	0.13a	0.65a	0.29a	8.47a	0.09a
G. Prairie2	3	3	0.34a	0.14a	0.08a	10.4a	14.7a	151a	17.1a	0.04a	0.14a	0.70a	0.36a	11.5a	0.09a
G. Prairie2	3	4	0.56a	0.20a	0.14a	13.6a	24.2a	194a	26.6a	0.07a	0.21a	1.25a	0.53a	16.3a	0.11a
G. Prairie2	3	5	0.56a	0.18a	0.13a	11.7a	20.0a	159a	21.3a	0.06a	0.18a	0.97a	0.38a	10.5a	0.13a
G. Prairie3	3	1	0.10a	0.02a	0.03a	34.5a	15.3a	157a	3.53a	0.04a	0.26a	0.10a	0.07a	0.10a	0.06a
G. Prairie3	3	2	0.10a	0.02a	0.07a	34.0a	15.9a	171a	2.46a	0.04a	0.22a	0.08a	0.08a	0.10a	0.07a
G. Prairie3	3	3	0.10a	0.03a	0.03a	27.1a	11.3a	254a	3.52a	0.04a	0.22a	0.08a	0.06a	0.13a	0.08a
G. Prairie3	3	4	0.10a	0.04a	0.04a	27.1a	11.7a	234a	3.83a	0.04a	0.21a	0.10a	0.06a	0.24a	0.08a
G. Prairie3	3	5	0.10a	0.04a	0.03a	26.2a	11.3a	261a	3.95a	0.04a	0.20a	0.10a	0.06a	0.19a	0.07a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Concluded. Comparison of the mean values by horizontal position of the chemical properties of the freshwater gel liquid phase samples.

Location	N	Hole No.	Ni	Se	Co	S	Si	As
			(mg/L)					
Cold Lake	2	4	0.1a*	0.1a	0.1a	40.2a	8.25a	0.3a
Cold Lake	3	5	0.1a	0.1a	0.1a	40.4a	7.87a	0.3a
Cold Lake	3	6	0.1a	0.1a	0.1a	40.2a	8.13a	0.2a
Cold Lake	3	7	0.1a	0.1a	0.1a	40.2a	8.77a	0.2a
Cold Lake	3	8	0.1a	0.1a	0.1a	40.9a	8.80a	0.2a
Waterton	3	1	0.03a	0.30a	0.01a	163a	9.74a	0.37a
Waterton	3	2	0.03a	0.30a	0.01a	161a	9.25a	0.40a
Waterton	3	3	0.03a	0.30a	0.01a	175a	15.0a	0.46a
Waterton	3	4	0.03a	0.30a	0.01a	257a	31.8a	0.52a
Waterton	3	5	0.03a	0.30a	0.01a	244a	48.6a	0.51a
G. Prairie1	3	1	0.03a	0.30a	0.01a	783a	4.20a	0.11a
G. Prairie1	3	2	0.03a	0.30a	0.01a	142a	4.83a	0.08a
G. Prairie1	3	3	0.03a	0.30a	0.01a	176a	3.93a	0.12a
G. Prairie1	3	4	0.03a	0.30a	0.01a	84.7a	6.11a	0.04a
G. Prairie1	3	5	0.03a	0.30a	0.01a	71.4a	3.42a	0.03a
G. Prairie2	3	1	0.04a	0.78a	0.02a	26.3a	353a	0.26a
G. Prairie2	3	2	0.04a	0.57a	0.02a	18.7a	211a	0.22a
G. Prairie2	3	3	0.04a	0.51a	0.01a	25.9a	222a	0.26a
G. Prairie2	3	4	0.05a	0.84a	0.02a	32.0a	385a	0.28a
G. Prairie2	3	5	0.05a	0.73a	0.02a	26.9a	315a	0.30a
G. Prairie2	3	1	0.03a	0.30a	0.01a	21.2a	5.44a	0.15a
G. Prairie2	3	2	0.03a	0.30a	0.02a	22.8a	5.13a	0.16a
G. Prairie2	3	3	0.03a	0.30a	0.02a	27.5a	5.26a	0.20a
G. Prairie2	3	4	0.03a	0.30a	0.01a	27.0a	12.4a	0.21a
G. Prairie2	3	5	0.03a	0.30a	0.01a	32.4a	5.82a	0.18a

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* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by horizontal position of the chemical properties of the invert waste liquid samples.

Location	N	Hole No.	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu	Pb
					(mg/L)												
Rocky Mtn.	2	1	7.90a*	3.65a	250a	248a	1.75a	0.04a	1750a	1.91a	0.02a	0.01a	0.03a	0.01a	0.01a	0.05a	0.10a
Rocky Mtn.	2	2	8.95a	4.18a	252a	197a	51.1a	3.98a	3470a	5.79a	0.02a	0.01a	0.03a	0.01a	0.01a	0.15a	0.10a
Rocky Mtn.	2	3	8.80a	5.62a	178a	156a	21.3a	0.82a	2430a	3.26a	0.02a	0.01a	0.03a	0.01a	0.01a	0.16a	0.10a
Rocky Mtn.	2	4	7.65a	2.77a	316a	314a	1.38a	0.02a	1060a	0.95a	0.02a	0.01a	0.03a	0.01a	0.01a	0.04a	0.10a
Rocky Mtn.	2	5	7.35a	2.39a	325a	324a	1.01a	0.02a	951a	0.72a	0.02a	0.01a	0.03a	0.01a	0.01a	0.02a	0.10a
G. Prairie	3	1	7.50a	2.51a	254a	253a	1.00a	0.02a	694a	1.34a	0.02a	0.11a	0.03a	0.02a	0.01a	0.01a	0.10a
G. Prairie	3	2	7.37a	2.21a	250a	250a	0.55a	0.01a	656a	1.14a	0.02a	0.07a	0.03a	0.02a	0.01a	0.01a	0.10a
G. Prairie	3	3	7.17a	2.45a	241a	241a	0.40a	0.01a	707a	1.25a	0.02a	0.06a	0.03a	0.02a	0.01a	0.01a	0.10a
G. Prairie	3	4	7.13a	2.67a	243a	242a	0.36a	0.01a	752a	1.39a	0.02a	0.08a	0.03a	0.02a	0.01a	0.01a	0.10a
G. Prairie	3	5	7.13a	2.88a	259a	259a	0.40a	0.01a	796a	1.43a	0.02a	0.06a	0.03a	0.02a	0.01a	0.01a	0.10a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Co	S	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se
	(mg/L)															
Rocky Mtn.	0.01a	39.5a	0.09a	0.07a	560a	24.7a	616a	43.2a	0.35a	9.78a	0.23a	0.65a	0.10a	0.05a	0.03a	0.30a
Rocky Mtn.	0.01a	42.9a	0.13a	0.04a	1360a	12.1a	761a	79.7a	0.39a	19.5a	0.81a	0.65a	0.19a	0.05a	0.05a	0.30a
Rocky Mtn.	0.01a	40.3a	0.13a	0.03a	919a	17.7a	634a	55.6a	0.32a	12.5a	0.38a	0.60a	0.11a	0.05a	0.04a	0.30a
Rocky Mtn.	0.01a	31.8a	0.08a	0.08a	286a	22.1a	523a	29.4a	0.30a	4.37a	0.13a	0.73a	0.10a	0.05a	0.03a	0.30a
Rocky Mtn.	0.01a	30.4a	0.08a	0.09a	232a	18.2a	525a	25.9a	0.30a	3.73a	0.12a	0.76a	0.10a	0.05a	0.03a	0.30a
G. Prairie	0.01a	74.3a	0.03a	0.13a	354a	19.3a	318a	9.23a	0.06a	0.78a	0.22a	0.14a	0.19a	0.05a	0.03a	0.30a
G. Prairie	0.01a	70.9a	0.03a	0.10a	315a	18.6a	302a	9.00a	0.07a	0.75a	0.19a	0.14a	0.13a	0.05a	0.03a	0.30a
G. Prairie	0.01a	71.7a	0.03a	0.11a	342a	18.8a	298a	8.89a	0.06a	0.74a	0.20a	0.14a	0.14a	0.05a	0.03a	0.30a
G. Prairie	0.01a	82.8a	0.08a	0.16a	407a	23.0a	323a	10.5a	0.09a	1.05a	0.24a	0.15a	0.62a	0.05a	0.05a	0.30a
G. Prairie	0.01a	81.3a	0.05a	0.16a	446a	24.0a	321a	10.8a	0.10a	1.20a	0.25a	0.15a	0.48a	0.05a	0.03a	0.30a

Location	Si	As
	(mg/L)	
Rocky Mtn.	8.80a	0.19a
Rocky Mtn.	6.09a	0.14a
Rocky Mtn.	6.72a	0.12a
Rocky Mtn.	7.25a	0.22a
Rocky Mtn.	6.78a	0.26a
G. Prairie	10.0a	0.16a
G. Prairie	9.18a	0.15a
G. Prairie	9.11a	0.16a
G. Prairie	12.1a	0.15a
G. Prairie	12.7a	0.15a

Comparison of the mean values by horizontal position of the chemical properties of the KCl liquid phase samples.

Location	N	Hole No.	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu	Pb
											(mg/L)						
Cold Lake	3	1	8.28a*	10.0a	108a	106a	1.91a	0.10a	5050a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	2	8.21a	10.1a	107a	105a	1.62a	0.08a	4970ab	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	3	8.22a	10.0a	109a	108a	1.69a	0.08a	4900b	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	4	8.15a	9.96a	109a	108a	1.44a	0.07a	4900b	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	5	8.18a	9.97a	108a	107a	1.61a	0.08a	4800b	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Waterton	3	1	7.73a	23.9a	299a	297a	1.87a	0.03a	9160a	2.71a	0.02a	1.11a	0.03a	0.01a	0.01a	0.01a	0.01a
Waterton	3	2	8.03a	23.5a	282a	276a	5.81a	0.12a	9190a	2.54a	0.02a	1.23a	0.03a	0.01a	0.01a	0.01a	0.01a
Waterton	3	3	8.27a	25.5a	274a	255a	19.0a	0.54a	9370a	3.93a	0.02a	1.10a	0.03a	0.01a	0.01a	0.01a	0.01a
Waterton	3	4	7.87a	25.1a	310a	306a	3.95a	0.06a	9320a	2.56a	0.02a	1.22a	0.03a	0.01a	0.01a	0.01a	0.01a
Waterton	3	5	7.50a	23.7a	292a	291a	0.86a	0.02a	9170a	2.60a	0.02a	1.54a	0.03a	0.01a	0.01a	0.01a	0.01a

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se	Co	S
								(mg/L)								
Cold Lake	0.1a	0.1a	75.5a	20.1a	2160a	1930a	0.3a	1.9a	0.4a	4.6a	0.1a	0.1a	0.1a	0.1a	0.1a	77.5a
Cold Lake	0.1a	0.1a	73.7a	20.6a	2150a	1920a	0.3a	1.9a	0.4a	4.5a	0.1a	0.1a	0.1a	0.1a	0.1a	77.0a
Cold Lake	0.1a	0.1a	75.8a	21.1a	2200a	1960a	0.3a	1.9a	0.4a	4.6a	0.1a	0.1a	0.1a	0.1a	0.1a	78.9a
Cold Lake	0.1a	0.1a	76.8a	21.5a	2330a	1990a	0.3a	1.9a	0.4a	4.6a	0.1a	0.1a	0.1a	0.1a	0.1a	79.8a
Cold Lake	0.1a	0.1a	74.8a	20.9a	2160a	1950a	0.3a	1.9a	0.4a	4.6a	0.1a	0.1a	0.1a	0.1a	0.1a	77.5a
Waterton	0.18a	1.99a	680a	134a	1920a	6570a	0.33a	12.0a	0.09a	0.42a	0.28a	0.05a	0.03a	0.30a	0.01a	453a
Waterton	0.18a	1.66a	661a	133a	1950a	6660a	0.33a	11.7a	0.07a	0.41a	0.32a	0.05a	0.03a	0.30a	0.01a	458a
Waterton	0.18a	1.48a	721a	125a	1940a	6600a	0.36a	12.7a	0.07a	0.34a	0.33a	0.06a	0.03a	0.30a	0.01a	455a
Waterton	0.18a	1.55a	671a	123a	1950a	6730a	0.32a	11.9a	0.07a	0.35a	0.31a	0.06a	0.03a	0.30a	0.01a	461a
Waterton	0.19a	2.20a	669a	135a	1900a	6510a	0.33a	11.9a	0.11a	0.42a	0.35a	0.05a	0.03a	0.30a	0.01a	455a

Location	Si	As
	(mg/L)	
Cold Lake	3.8a	0.1a
Cold Lake	3.8a	0.1a
Cold Lake	3.8a	0.1a
Cold Lake	3.9a	0.1a
Cold Lake	3.9a	0.1a
Waterton	6.38a	0.13a
Waterton	7.18a	0.11ab
Waterton	7.82a	0.08ab
Waterton	7.27a	0.05b
Waterton	5.91a	0.07ab

Comparison of the mean values by horizontal position of the chemical properties of the NaCl liquid phase samples.

Location	N	Hole No.	pH	E.C. (dS/m)	Alk.	HCO3	CO3	OH	Cl	Al	Cr	Fe	V	Ti	Cd	Cu
					(mg/L)											
Cold Lake	3	1	9.77a*	22.4a	252a	161a	71.5a	20.0a	13300a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	2	9.53a	22.7a	257a	182a	64.3a	11.3a	13100a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	3	9.96a	33.3a	502a	174a	121a	116a	21000a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	4	9.97a	36.2a	523a	175a	237a	111a	21900a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	3	5	10.1a	45.7a	542a	162a	262a	119a	23200a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Slave Lake	3	1	8.15a	1.70a	62.7a	61.8ab	0.82a	0.07a	458a	0.31b	0.02a	0.03b	0.03a	0.02a	0.01a	0.0220ab
Slave Lake	3	2	8.48a	1.68ab	62.3a	59.6abc	2.51a	0.22a	489a	0.30b	0.02a	0.03b	0.03a	0.01a	0.01a	0.0183ab
Slave Lake	3	3	8.63a	1.77a	72.5a	67.1a	5.07a	0.34a	493a	0.30b	0.02a	0.02b	0.03a	0.01a	0.01a	0.0193ab
Slave Lake	3	4	6.68a	0.85b	11.6a	11.6bc	0.01a	0.00a	231b	0.64a	0.02a	0.72a	0.03a	0.01a	0.01a	0.0250a
Slave Lake	3	5	6.65a	0.85b	8.02a	8.01c	0.00a	0.00a	224b	0.77a	0.02a	0.97a	0.03a	0.01a	0.01a	0.0180b

E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/L); * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Pb	Zn	Mn	Ca	Mg	Na	K	Li	Sr	Ba	B	P	Mo	Ni	Se
	(mg/L)														
Cold Lake	0.1a	0.1a	0.1a	22.2a	4.8a	9060a	136a	0.1a	1.0a	0.1a	0.1a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	25.2a	5.7a	8990a	120a	0.1a	1.0a	0.1a	0.2a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	96.1a	5.3a	13800a	190a	0.1a	1.6a	0.1a	0.2a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	93.4a	4.6a	13500a	170a	0.1a	1.6a	0.1a	0.2a	0.1a	0.1a	0.1a	0.1a
Cold Lake	0.1a	0.1a	0.1a	84.3a	4.3a	14300a	181a	0.1a	2.1a	0.2a	0.1a	0.1a	0.1a	0.1a	0.1a
Slave Lake	0.10a	0.05a	0.01b	33.7a	6.17b	315a	9.91a	0.04a	0.33a	0.08b	0.057a	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.10a	0.05a	0.01b	36.3a	6.18b	326a	10.4a	0.04a	0.37a	0.08b	0.055ab	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.10a	0.05a	0.01b	37.6a	6.25b	330a	10.8a	0.04a	0.39a	0.08b	0.057a	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.10a	0.03a	0.32a	55.6a	12.6a	106b	2.40b	0.04a	0.30a	0.14a	0.047ab	0.10a	0.05a	0.03a	0.30a
Slave Lake	0.10a	0.02a	0.29a	57.8a	12.3a	103b	2.23b	0.04a	0.29a	0.14a	0.045b	0.10a	0.05a	0.03a	0.30a

Location	Co	S	Si	As
	(mg/L)			
Cold Lake	0.1a	98.8a	6.6a	0.1a
Cold Lake	0.1a	99.3a	6.9a	0.1a
Cold Lake	0.1a	119a	6.7a	0.1a
Cold Lake	0.1a	145a	6.7a	0.1a
Cold Lake	0.1a	153a	6.8a	0.1a
Slave Lake	0.01a	20.3a	1.52b	0.04a
Slave Lake	0.01a	20.4a	1.53b	0.04a
Slave Lake	0.01a	20.6a	1.48b	0.04a
Slave Lake	0.01a	25.3a	4.22a	0.03a
Slave Lake	0.01a	24.7a	4.56a	0.03a

10.3 COMPARISON OF THE MEAN VALUES BY DEPTH OF THE CHEMICAL AND PHYSICAL PROPERTIES OF THE SOLID PHASE SAMPLES

Comparison of the mean values by depth of the chemical and physical properties for the DAP solid phase samples.

Location	N	Depth (cm)	pH		ANC	$CaCO_3$ Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H_2O	$CaCl_2$	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Cold Lake	7	0-30	10.3a*	10.2a	16.6a	8.07a	14.5a	7.00a	479a	18.2a	24.2a	3.15a	0.97a	2.18a	0.63a	99.7a
Cold Lake	7	30-60	10.6a	10.5a	17.6a	8.46a	13.8a	4.92a	653a	18.1a	21.5a	2.22ab	1.02a	1.20ab	0.27a	99.8a
Cold Lake	6	60-90	10.3a	9.95a	13.6a	6.98a	7.47a	1.93a	511a	14.2a	15.3a	1.71ab	0.84a	0.87b	0.15a	68.7a

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sand	Silt	Clay
	(%)		
Cold Lake	40a	39a	21a
Cold Lake	50a	33a	17a
Cold Lake	60a	30a	11a

Comparison of the mean values by depth of the chemical and physical properties for the freshwater gel solid phase samples.

Location	Waste	N	Depth	pH		ANC	$CaCO_3$	Extractable Ions					TC	TIC	TOC
							Eq	Na	K	Ca	Mg	CEC			
			(cm)	H_2O	$CaCl_2$	(%)		(meq/100 g)					(%)		
Cold Lake	Freshwater	5	0–75	9.78a*	10.0a	17.9a	6.64a	16.8a	1.64a	112a	8.08a	28.0a	4.12a	0.80a	3.32a
Cold Lake	Freshwater	5	75–150	10.1a	10.1a	11.0a	5.40a	15.0a	1.24a	61.9a	5.00a	23.0a	3.59a	0.65a	2.94a
Cold Lake	Freshwater	5	150–225	9.34a	9.36a	7.33a	5.19a	17.3a	1.24a	53.5a	4.19a	23.5a	3.33a	0.62a	2.70a
Rocky Mtn.	Freshwater	4	0–50	9.35a	8.88a	4.34a	4.65a	6.27a	0.43a	19.3a	1.35a	7.03a	4.05a	0.56a	3.50a
Rocky Mtn.	Freshwater	1	50–125	9.60a	9.00a	3.05a	3.05a	6.01a	0.47a	14.9a	1.45a	6.50a	2.38a	0.37a	2.01a
Rocky Mtn.	Freshwater	1	125–200	9.40a	9.10a	11.3a	9.73a	6.33a	0.57a	25.3a	1.47a	7.50a	3.49a	1.17a	2.32a
Rocky Mtn.	Water–N.A.	3	0–50	7.87a	7.90a	61.2a	63.8a	2.31a	1.13a	94.3a	8.57a	5.87a	9.81a	7.65a	2.16a
Rocky Mtn.	Water–N.A.	3	50–100	7.97a	8.10a	57.1a	54.8a	2.50a	0.76a	336a	7.54a	7.67a	8.38a	6.57a	1.81a
Waterton	Freshwater	5	0–100	9.96a	9.56a	7.87a	4.96a	279a	3.71a	29.5a	1.85a	40.9a	6.26a	0.60a	5.67a
Waterton	Freshwater	5	100–225	9.86a	9.48a	6.99a	4.64a	115a	6.42a	35.6a	2.82a	36.0a	3.01a	0.56a	2.45a
Waterton	Freshwater	5	225–350	9.60a	9.30a	7.56a	4.57a	30.7a	3.34a	34.4a	3.07a	27.1a	2.53a	0.55a	1.98a
G. Prairie1	Freshwater	5	0–75	9.10a	8.92a	13.0a	10.9a	54.2a	0.95a	46.8a	2.66a	22.6a	2.94a	1.31a	1.64a
G. Prairie1	Freshwater	5	75–150	9.08a	9.44a	9.04a	8.00a	29.0a	0.92a	51.7a	3.27a	20.4a	2.36a	0.95a	1.42a
G. Prairie1	Freshwater	5	150–225	9.40a	9.24a	8.42a	6.89a	25.1a	0.99a	56.5a	3.28a	19.4a	2.09a	0.83a	1.26a
G. Prairie2	Freshwater	4	0–30	8.98a	8.78a	3.15a	2.33a	9.98a	0.68a	40.5a	2.25a	17.0a	1.46a	0.28a	1.18a
G. Prairie2	Freshwater	4	30–75	8.20a	8.33a	3.18a	2.20a	7.79a	0.62a	34.1a	2.51a	13.8a	1.82a	0.26a	1.56a

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Waste	Oil	Water	Sand	Silt	Clay
				(%)		
Cold Lake	Freshwater	1.53a	162a	37a	39a	25a
Cold Lake	Freshwater	1.27a	170a	42a	35a	24a
Cold Lake	Freshwater	1.20a	171a	39a	36a	25a
Rocky Mtn.	Freshwater	0.05a	32.1a	58a	31a	11a
Rocky Mtn.	Freshwater	0.04a	27.0a	63a	29a	8a
Rocky Mtn.	Freshwater	0.02a	24.5a	68a	23a	9a
Rocky Mtn.	Water–N.A.	0.06a	43.0a	31a	54a	15a
Rocky Mtn.	Water–N.A.	0.08a	63.5a	32a	54a	20a
Waterton	Freshwater	3.57a	540a	7a	12a	81a
Waterton	Freshwater	2.47a	444a	18a	17a	66a
Waterton	Freshwater	0.45a	323a	27a	23a	50a
G. Prairie1	Freshwater	0.41a	247a	14a	40a	46a
G. Prairie1	Freshwater	0.20a	194a	28a	35a	36a
G. Prairie1	Freshwater	0.15a	178a	29a	37a	34a
G. Prairie2	Freshwater	0.14a	192a	14a	54a	32a
G. Prairie2	Freshwater	0.10a	67.5a	25a	49a	26a

Comparison of the mean values by depth of the chemical and physical properties for the invert solid phase samples.

Location	N	Depth (cm)	pH		ANC	CaCO3 Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H2O	CaCl2	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Rocky Mtn.	6	0-50	7.83a*	7.95a	4.97a	4.11a	7.72a	1.41a	50.1a	2.22a	9.87a	7.66a	0.49a	7.17a	3.61a	14.8a
Rocky Mtn.	2	50-100	8.20a	8.35a	6.21a	4.92a	7.67a	1.62a	55.3a	2.19a	10.3a	9.30a	0.49a	8.71a	3.97a	14.3a
Rocky Mtn.	1	100-150	8.00a	8.20a	5.18a	3.92a	7.89a	1.44a	55.9a	2.55a	10.9a	7.77a	0.47a	7.30a	3.14a	15.5a
G. Prairie	6	0-50	9.75a	9.55a	4.73a	4.20a	8.76a	1.34a	58.6a	1.23a	12.9a	10.4a	0.50a	9.86a	7.62a	19.8a
G. Prairie	5	50-125	9.84a	9.56a	7.99a	3.98a	8.49a	1.34a	56.6a	1.23a	12.5a	9.63a	0.48a	9.15a	7.77a	19.2a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sand	Silt	Clay
		(%)	
Rocky Mtn.	41a	40a	19a
Rocky Mtn.	38a	44a	18a
Rocky Mtn.	38a	40a	22a
G. Prairie	45a	38a	17a
G. Prairie	53a	32a	14a

Comparison of the mean values by depth of the chemical and physical properties for the KCl solid phase samples.

Location	N	Depth (cm)	pH		ANC	CaCO3 Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H2O	CaCl2	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Waterton	5	0–75	8.10a*	8.24a	10.8a	8.58a	35.4a	471a	65.2a	13.4a	16.7a	11.1a	1.03a	10.1a	7.10a	259a
Waterton	5	75–175	8.42a	8.56a	9.65a	7.62a	32.3a	397ab	80.9a	15.1a	18.9a	5.30a	0.91a	4.39a	2.25a	219a
Waterton	5	175–275	8.56a	8.62a	11.75a	10.5a	23.2a	291b	75.7a	17.2a	14.7a	5.00a	1.26a	3.74a	2.13a	147a
Cold Lake	5	0–75	9.00a	9.28a	7.92a	4.91a	16.3a	32.9a	33.8a	1.82a	19.6a	4.89a	0.59a	4.30a	2.25a	89.6a
Cold Lake	5	75–120	8.94a	9.28a	8.92a	5.33a	13.2a	26.9a	38.2a	2.19a	19.5a	3.78a	0.64a	3.14a	1.30a	73.0a
Cold Lake	4	150–225	8.95a	9.25a	8.53a	4.99a	14.1a	24.3a	51.1a	2.79a	21.1a	4.08a	0.60a	3.47a	1.28a	77.2a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sand	Silt	Clay
	(%)		
Waterton	36a	31a	33a
Waterton	26a	38a	35a
Waterton	27a	41a	32a
Cold Lake	43a	39a	18a
Cold Lake	43a	34a	23a
Cold Lake	43a	34a	23a

Comparison of the mean values by depth of the chemical and physical properties for the NaCl solid phase samples.

Location	N	Depth (cm)	pH		ANC	CaCO3 Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H2O	CaCl2	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Slave Lake	4	0–20	9.08a*	8.98a	16.5a	10.7a	13.6a	0.75a	90.7a	9.43a	17.5a	3.01a	1.28a	1.73a	0.30a	23.8a
Slave Lake	1	0–50	8.30a	8.60a	32.9a	27.5a	74.9a	0.82a	132a	25.6a	13.4a	7.31a	3.31a	4.01a	1.15a	24.5a
Slave Lake	2	20–30	8.80a	9.03a	29.7a	23.8a	22.6a	0.53a	149a	14.9a	12.0a	4.55a	2.86a	1.69a	0.35a	24.8a
Slave Lake	1	20–50	9.40a	9.30a	24.8a	16.5a	67.1a	0.88a	203a	10.8a	22.9a	4.34a	1.98a	2.36a	0.55a	14.7a
Slave Lake	2	50–100	8.45a	8.70a	31.9a	28.8a	89.4a	0.77a	237a	20.6a	5.65a	6.30a	3.46a	2.84a	1.04a	22.4a
Cold Lake	5	0–75	10.4a	10.6a	23.1a	11.0a	138a	0.99a	104a	10.3a	19.2a	2.82a	1.32a	1.50a	0.26a	82.8a
Cold Lake	5	75–150	9.40a	9.74a	17.4a	9.53a	92.2a	0.60ab	66.1b	5.63b	16.0b	2.25a	1.14a	1.11a	0.18a	47.9a
Cold Lake	5	150–225	8.72a	9.14a	16.3a	7.94a	75.4a	0.51b	51.9b	3.97b	14.4b	2.09a	0.92a	1.14a	0.19a	39.5a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sand	Silt	Clay
		(%)	
Slave Lake	32a	44a	24a
Slave Lake	35a	40a	25a
Slave Lake	50a	40a	10a
Slave Lake	40a	38a	22a
Slave Lake	59a	31a	10a
Cold Lake	53a	34a	13a
Cold Lake	54a	31a	15a
Cold Lake	48a	35a	17a

10.4 COMPARISON OF THE MEAN VALUES BY HORIZONTAL POSITION OF THE CHEMICAL AND PHYSICAL PROPERTIES OF THE SOLID PHASE SAMPLES

Comparison of the mean values by horizontal position of the chemical and physical properties for the DAP solid phase samples.

Location	N	Hole No.	pH		ANC	CaCO3 Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H2O	CaCl2	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Cold Lake	3	1	12.1a*	12.1a	32.3a	13.3a	14.4a	7.53ab	1430a	42.1a	23.2a	2.76a	1.60a	1.16a	0.32a	106a
Cold Lake	2	2	12.1a	12.1a	30.4a	12.9a	21.4a	15.0a	1330a	42.7a	25.5a	2.90a	1.55a	1.34a	0.49a	134a
Cold Lake	3	3	8.70b	8.47b	3.75b	3.26b	14.8a	0.84b	27.8b	2.73b	22.8a	2.14a	0.39b	1.75a	0.15a	50.4a
Cold Lake	3	4	11.5a	11.3ab	22.0a	10.8a	9.36a	5.61ab	696ab	18.5b	24.5a	2.69a	1.29a	1.40a	0.31a	87.4a
Cold Lake	3	5	11.3a	10.9b	21.2a	10.8a	10.0a	5.71ab	584ab	17.8b	23.7a	2.63a	1.30a	1.33a	0.30a	119a
Cold Lake	3	6	8.97b	8.67c	3.78b	2.71b	9.72a	1.21b	19.9b	1.83b	14.5a	2.05a	0.33b	1.72a	0.65a	72.6a
Cold Lake	3	7	8.83b	8.57c	3.93b	3.02b	8.37a	0.78b	19.4b	1.66b	11.5a	1.73a	0.36b	1.37a	0.34a	78.6a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Sand	Silt	Clay
			(%)		
Cold Lake	3	1	42a	48a	10a
Cold Lake	2	2	36a	48a	16a
Cold Lake	3	3	37a	33ab	30a
Cold Lake	3	4	55a	36ab	9a
Cold Lake	3	5	51a	38ab	11a
Cold Lake	3	6	57a	22b	21a
Cold Lake	3	7	63a	18b	19a

Comparison of the mean values by horizontal position of the chemical and physical properties for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	pH		ANC	$CaCO_3$ Eq	Extractable Ions					TC	TIC	TOC
				H_2O	$CaCl_2$	(%)		Na	K	Ca	Mg	CEC	(%)		
								(meq/100 g)							
Cold Lake	Freshwater	3	1	10.8a*	10.6a	11.3a	7.39a	14.8a	1.71a	106a	9.08a	27.1a	3.68a	0.89a	2.79a
Cold Lake	Freshwater	3	2	10.9a	10.9a	22.9a	7.96a	13.8a	2.09a	163a	12.1a	28.9a	3.18a	0.96a	2.22a
Cold Lake	Freshwater	3	3	10.1a	10.2a	11.4a	6.41a	15.3a	1.26a	67.2a	5.40a	23.5a	3.42a	0.77a	2.65a
Cold Lake	Freshwater	3	4	8.5a	8.8a	7.46a	3.61a	21.1a	0.98a	20.4a	1.07a	22.8a	4.06a	0.43a	3.62a
Cold Lake	Freshwater	3	5	8.5a	8.6a	7.38a	3.35a	16.8a	0.83a	22.1a	1.11a	21.8a	4.07a	0.40a	3.67a
Rocky Mtn.	Freshwater	3	18	9.50a	9.03ab	6.06a	5.56a	5.99a	0.52a	18.2a	1.44a	6.80a	2.55a	0.67a	1.88b
Rocky Mtn.	Freshwater	1	19	8.90a	8.40b	2.10a	1.84a	4.89a	0.24a	13.8a	1.17a	4.70a	1.23a	0.22a	1.01b
Rocky Mtn.	Freshwater	1	20	9.30a	8.90ab	6.52a	7.71a	7.15a	0.50a	26.2a	1.49a	8.20a	3.06a	0.93a	2.14b
Rocky Mtn.	Freshwater	1	21	9.70a	9.20a	4.92a	5.13a	7.41a	0.47a	22.6a	1.33a	8.80a	10.2a	0.62a	9.53a
Rocky Mtn.	Water–N.A.	2	6	7.65a	7.85a	60.4a	58.1a	2.4a	1.24a	107a	9.98a	6.05a	9.03a	6.98a	2.05a
Rocky Mtn.	Water–N.A.	2	7	8.10a	8.15a	57.0a	55.5a	7.0a	1.02a	107a	7.05a	8.3a	8.4a	6.67a	1.75a
Rocky Mtn.	Water–N.A.	2	8	6.00a	8.00a	60.1a	64.1a	2.34a	0.58a	431a	7.2a	5.96a	9.9a	7.69a	2.16a
Waterton	Freshwater	3	1	9.83a	9.30a	4.89b	3.23ab	37.3a	6.70a	26.3a	1.67a	36.0a	2.1a	0.39ab	1.71a
Waterton	Freshwater	3	2	9.67a	9.23a	6.06ab	3.07a	43.1a	3.62a	29.2a	2.42a	39.5a	2.88a	0.37b	2.52a
Waterton	Freshwater	3	3	10.1a	9.73a	7.84ab	5.23ab	281a	2.09a	30.0a	1.79a	42.0a	4.02a	0.63ab	3.39a
Waterton	Freshwater	3	4	9.73a	9.53a	9.64a	5.17ab	165a	2.35a	31.7a	1.58a	24.6a	5.16a	0.62ab	4.54a
Waterton	Freshwater	3	5	9.70a	9.43a	8.93ab	6.91a	182a	7.68a	48.7a	5.42a	31.4a	5.51a	0.83a	4.68a
G.Prairie1	Freshwater	3	6	9.10a	9.00a	8.83a	7.53a	27.4a	1.09a	37.8a	2.19a	18.7a	2.79a	0.90a	1.89a
G.Prairie1	Freshwater	3	7	9.57a	9.27a	5.15a	3.75a	14.0a	0.89a	56.4a	4.17a	21.2a	1.49a	0.45a	1.04a
G.Prairie1	Freshwater	3	8	10.1a	10.2a	5.67a	3.44a	18.2a	0.99a	63.0a	3.39a	24.1a	1.51a	0.41a	1.10a
G.Prairie1	Freshwater	3	9	9.17a	9.00a	14.9a	13.2a	55.3a	0.89a	48.3a	2.40a	19.7a	3.16a	1.58a	1.58a
G.Prairie1	Freshwater	3	10	8.03a	8.57a	16.2a	14.9a	65.5a	0.91a	53.0a	3.19a	20.3a	3.37a	1.79a	1.59a
G.Prairie2	Freshwater	2	6	8.80a	8.80a	2.87a	1.44a	6.65a	0.63a	42.4a	3.17a	12.9a	1.51a	0.17a	1.34a
G.Prairie2	Freshwater	2	7	9.30a	9.20a	4.49a	2.92a	8.38a	0.64a	51.1a	3.03a	17.6a	1.53a	0.35a	1.18a
G.Prairie2	Freshwater	2	8	8.30a	8.40a	2.50a	2.29a	11.9a	0.69a	26.1a	1.20a	16.0a	1.99a	0.27a	1.71a
G.Prairie2	Freshwater	2	9	7.95a	7.80a	2.80a	2.40a	8.59a	0.65a	29.6a	2.12a	15.3a	1.54a	0.29a	1.25a

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Concluded. Comparison of the mean values by horizontal position of the chemical and physical properties for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Oil	Water	Sand	Silt	Clay
				(%)				
Cold Lake	Freshwater	3	1	0.94a*	101b	44a	38a	18b
Cold Lake	Freshwater	3	2	0.94a	143ab	48a	37a	15b
Cold Lake	Freshwater	3	3	1.18a	149ab	43a	42a	15b
Cold Lake	Freshwater	3	4	1.75a	245a	30a	34a	36a
Cold Lake	Freshwater	3	5	1.86a	198ab	32a	32a	36a
Rocky Mtn.	Freshwater	3	18	0.03a	25.0b	61a	30a	9a
Rocky Mtn.	Freshwater	1	19	0.03a	22.8b	69a	22a	9a
Rocky Mtn.	Freshwater	1	20	0.07a	34.1ab	52a	34a	14a
Rocky Mtn.	Freshwater	1	21	0.05a	46.8a	58a	29a	13a
Rocky Mtn.	Water-N.A.	2	6	0.07a	75.5a	31a	58a	21a
Rocky Mtn.	Water-N.A.	2	7	0.08a	74.4a	33a	52a	15a
Rocky Mtn.	Water-N.A.	2	8	0.07a	40.0a	31a	53a	16a
Waterton	Freshwater	3	1	0.53a	364a	7a	16a	77a
Waterton	Freshwater	3	2	0.93a	508a	5a	11a	84a
Waterton	Freshwater	3	3	1.12a	468a	9a	10a	81a
Waterton	Freshwater	3	4	5.03a	416a	37a	23a	40a
Waterton	Freshwater	3	5	3.21a	423a	29a	24a	47a
G.Prairie1	Freshwater	3	6	0.29a	57.5a	39a	32a	29a
G.Prairie1	Freshwater	3	7	0.24a	154a	27a	41a	32a
G.Prairie1	Freshwater	3	8	0.12a	306a	15a	39a	46a
G.Prairie1	Freshwater	3	9	0.52a	261a	25a	36a	39a
G.Prairie1	Freshwater	3	10	0.08a	254a	14a	39a	47a
G.Prairie2	Freshwater	2	6	0.08a	88.8a	11a	66a	23a
G.Prairie2	Freshwater	2	7	0.11a	146a	12a	48a	40a
G.Prairie2	Freshwater	2	8	0.20a	210a	38a	42a	20a
G.Prairie2	Freshwater	2	9	0.10a	74.0a	18a	48a	34a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by horizontal position of the chemical and physical properties for the invert solid phase samples.

Location	N	Hole No.	pH		ANC	$CaCO_3$ Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H_2O	$CaCl_2$	(%)		Na	K	Ca	Mg	CEC			(%)		
							(meq/100 g)									
Rocky Mtn.	2	12	7.85a*	8.50a	5.91a	4.97a	7.20a	1.44a	52.3a	2.22a	10.3a	8.59a	0.60a	7.99a	3.32a	13.0a
Rocky Mtn.	1	13	7.80a	8.00a	5.68a	4.95a	7.94a	1.39a	55.0a	2.23a	10.4a	6.59a	0.59a	6.00a	3.13a	14.2a
Rocky Mtn.	1	14	7.90a	7.90a	6.65a	5.46a	7.00a	1.18a	54.7a	2.32a	9.7a	8.49a	0.66a	7.84a	4.34a	19.6a
Rocky Mtn.	3	15	8.10a	8.23a	5.02a	3.91a	8.16a	1.67a	54.3a	2.36a	10.7a	8.40a	0.47a	7.93a	3.69a	14.4a
Rocky Mtn.	1	16	8.00a	8.10a	4.87a	3.99a	5.81a	1.21a	45.3a	1.78a	7.5a	7.22a	0.48a	6.74a	3.43a	13.3a
Rocky Mtn.	1	17	7.70a	7.80a	3.32a	2.35a	9.90a	1.46a	45.0a	2.43a	10.4a	7.66a	0.28a	7.38a	4.09a	16.5a
G. Prairie	1	6	10.7a	10.0a	5.22a	4.80a	9.12a	1.34a	69.5a	1.26ab	13.9a	11.3a	0.58a	10.7a	9.62a	20.9a
G. Prairie	2	7	9.95a	9.60a	3.95a	3.57a	8.48a	1.33a	59.4a	1.20b	13.3a	10.1a	0.43a	9.68a	8.13a	17.9a
G. Prairie	2	8	9.25a	9.40a	3.83a	3.38a	9.15a	1.28a	56.8a	1.31a	13.4a	8.67a	0.41a	8.26a	7.67a	20.5a
G. Prairie	2	9	9.85a	9.50a	6.19a	4.90a	8.65a	1.31a	55.8a	1.20b	12.0a	11.1a	0.59a	10.5a	7.05a	19.2a
G. Prairie	2	10	9.65a	9.50a	4.64a	4.23a	8.39a	1.41a	56.6a	1.19b	12.4a	9.81a	0.51a	9.30a	6.51a	19.7a
G. Prairie	2	11	9.80a	9.55a	5.46a	4.09a	8.28a	1.36a	53.9a	1.23ab	12.2a	9.81a	0.49a	9.31a	8.13a	19.9a

ANC = Acid Neutralizing Capacity; $CaCO_3$ Eq = Calcium carbonate equivalent (g $CaCO_3$ eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Sand	Silt	Clay
				(%)	
Rocky Mtn.	2	12	43a	38a	19a
Rocky Mtn.	1	13	41a	38a	21a
Rocky Mtn.	1	14	47a	33a	20a
Rocky Mtn.	3	15	39a	43a	18a
Rocky Mtn.	1	16	35a	48a	17a
Rocky Mtn.	1	17	35a	39a	26a
G. Prairie	1	6	48a	38a	14a
G. Prairie	2	7	49a	35a	16a
G. Prairie	2	8	40a	41a	19a
G. Prairie	2	9	50a	36a	14a
G. Prairie	2	10	58a	30a	12a
G. Prairie	2	11	47a	36a	17a

Comparison of the mean values by horizontal position of the chemical and physical properties for the KCl solid phase samples.

Location	N	Hole No.	pH		ANC	CaCO3 Eq	Extractable Ions					TC	TIC	TOC	Oil	Water
			H2O	CaCl2	(%)		Na	K	Ca	Mg	CEC	(%)				
							(meq/100 g)									
Cold Lake	3	1	7.9a*	8.2a	6.93a	4.85a	12.4a	25.8a	20.4a	0.98a	16.4a	4.02a	0.58a	3.43a	1.32a	67.3a
Cold Lake	2	2	9.1a	9.4a	8.76a	5.55a	13.5a	25.9a	41.8a	2.47a	22.5a	3.90a	0.67a	3.23a	1.56a	68.7a
Cold Lake	3	3	9.9a	10.1a	9.56a	5.55a	14.7a	27.4a	51.8a	2.86a	19.6a	4.07a	0.67a	3.40a	1.52a	80.8a
Cold Lake	3	4	9.8a	10.2a	10.0a	5.18a	14.9a	30.4a	65.6a	3.75a	22.9a	4.08a	0.62a	3.46a	1.46a	82.7a
Cold Lake	3	5	8.2a	8.5a	7.07a	4.42a	17.1a	31.1a	22.5a	1.16a	19.3a	5.11a	0.53a	4.58a	2.27a	97.4a
Waterton	3	1	8.73a	8.63a	8.66a	6.80a	23.8a	334a	64.3a	7.9a	26.4a	4.2a	0.82a	3,38a	2.37a	142a
Waterton	3	2	8.57a	8.70a	11.7a	10.0a	32.6a	401a	72.2a	14.9a	18.2a	7.32a	1.20a	6.12a	3.93a	233a
Waterton	3	3	8.40a	8.60a	12.6a	10.0a	35.3a	373a	74.3a	23.2a	12.3a	9.79a	1.21a	8.59a	4.48a	216a
Waterton	3	4	7.93a	8.13a	9.39a	9.09a	31.4a	362a	77.4a	14.6a	14.5a	7.52a	1.09a	6.43a	5.09a	194a
Waterton	3	5	8.17a	8.30a	11.3a	8.57a	28.5a	461a	81.5a	15.5a	12.4a	6.89a	1.03a	5.87a	3.26a	258a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Sand	Silt	Clay
			(%)		
Cold Lake	3	1	41a	36a	23a
Cold Lake	2	2	47a	34a	19a
Cold Lake	3	3	44a	34a	22a
Cold Lake	3	4	43a	38a	19a
Cold Lake	3	5	41a	36a	23a
Waterton	3	1	27a	34a	39a
Waterton	3	2	32a	38a	30a
Waterton	3	3	33a	38a	29a
Waterton	3	4	34a	37a	29a
Waterton	3	5	22a	37a	41a

Comparison of the mean values by horizontal position of the chemical and physical properties for the NaCl solid phase sample.

Location	N	Hole No.	pH H2O	pH CaCl2	ANC (%)	CaCO3 Eq (%)	Extractable Ions Na (meq/100 g)	Extractable Ions K (meq/100 g)	Extractable Ions Ca (meq/100 g)	Extractable Ions Mg (meq/100 g)	CEC (meq/100 g)	TC (%)	TIC (%)	TOC (%)	Oil (%)	Water (%)
Cold Lake	3	1	9.7a*	9.9a	14.1a	6.49a	59.3a	0.65a	74.2a	6.21a	16.6a	1.58a	0.78a	0.80a	0.15a	39.8a
Cold Lake	3	2	10.7a	10.9a	19.1a	8.83a	107a	0.66a	83.1a	7.14a	16.2a	1.99a	1.06a	0.93a	0.13a	35.2a
Cold Lake	3	3	9.5a	9.7a	22.8a	11.2a	144a	0.84a	77.6a	8.23a	17.2a	2.59a	1.34a	1.25a	0.26a	76.8a
Cold Lake	3	4	8.6a	9.0a	20.1a	9.92a	88.7a	0.66a	62.5a	4.51a	15.2a	2.74a	1.19a	1.55a	0.24a	64.4a
Cold Lake	3	5	9.1a	9.5a	18.5a	11.0a	110a	0.70a	73.0a	7.00a	17.3a	3.03a	1.32a	1.71a	0.29a	70.5a
Slave Lake	2	1	9.05a	9.25a	26.4a	16.8a	35.5a	0.68a	131a	13.4a	16.2a	3.70a	2.02a	1.68ab	0.21b	22.9a
Slave Lake	2	2	9.45a	9.28a	18.0a	13.5a	8.24a	0.85a	116a	9.90a	16.1a	2.98a	1.62a	1.36b	0.31b	25.3a
Slave Lake	2	3	8.30a	8.65a	31.0a	26.9a	99.2a	0.88a	203a	26.4a	8.30a	7.23a	3.23a	3.99a	1.33a	13.0a
Slave Lake	3	4	8.87a	8.90a	30.8a	24.8a	43.0a	0.61a	179a	13.8a	14.6a	5.28a	2.97a	2.31ab	0.55ab	21.3a
Slave Lake	1	5	8.30a	8.20a	3.78a	3.04a	5.22a	0.65a	32.7a	4.51a	16.6a	1.72a	0.37a	1.36b	0.33b	22.3a

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; TIC = Total Inorganic Carbon; TOC = Total Organic Carbon; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Sand (%)	Silt (%)	Clay (%)
Cold Lake	3	1	52a	31a	17a
Cold Lake	3	2	55a	31a	14a
Cold Lake	3	3	58a	31a	11a
Cold Lake	3	4	43a	41a	16a
Cold Lake	3	5	51a	35a	14a
Slave Lake	2	1	40a	44a	16a
Slave Lake	2	2	44a	39a	17a
Slave Lake	2	3	47a	27a	16a
Slave Lake	3	4	48a	38a	14a
Slave Lake	1	5	18a	42a	40a

10.5 COMPARISON OF THE MEAN VALUES BY DEPTH OF THE SATURATED PASTE EXTRACT DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by depth of the saturated paste extract data for the DAP solid phase samples.

Location	N	Depth (cm)	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S	Al	Cr
						(mg/L)												
Cold Lake	7	0–30	93.3a*	8.70a	10.3a	991a	205a	485a	301a	1530a	185a	2.37a	957a	552a	1.24a	533a	1.05a	0.12a
Cold Lake	7	30–60	97.7a	6.89a	10.5a	741a	166a	357a	219a	1220a	159a	1.11a	590a	312a	0.94a	292a	1.12a	0.07a
Cold Lake	6	60–90	64.4a	5.83a	10.2a	726a	219a	368a	139a	884a	138a	2.12a	360a	126a	0.97a	326a	1.10a	0.10a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (CaCO3); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo	Ni	Se	Co	Si
	(mg/L)															
Cold Lake	0.04a	0.11a	0.01a	0.03a	0.10a	0.16a	0.01a	0.13a	1.09a	0.23a	32.4a	0.83a	0.03a	0.30b	0.01a	12.0a
Cold Lake	0.02a	0.08a	0.01a	0.02a	0.10a	0.14a	0.01a	0.07a	1.07a	0.12a	13.5a	0.62a	0.03a	0.30b	0.01a	6.78a
Cold Lake	0.03a	0.10a	0.01a	0.02a	0.10a	0.12a	0.01a	0.09a	0.91a	0.12a	13.7a	0.83a	0.04a	0.30a	0.01a	13.5a

Location	As	SAR
	(mg/L)	
Cold Lake	0.27a	34.7a
Cold Lake	0.24a	18.3a
Cold Lake	0.26a	15.4a

Comparison of the mean values by depth of the saturated paste extract data for the freshwater gel solid phase samples.

Location	Waste	N	Depth (cm)	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl (mg/L)	Ca	Mg	Na	K
Cold Lake	Freshwater	5	0-75	116a*	8.87a	9.72a	508a	128a	289a	90.1a	1210a	264a	3.15a	1910a	108a
Cold Lake	Freshwater	5	75-150	102a	6.67a	9.89a	214a	96.2a	90.7a	26.5a	1030a	118a	0.74a	1830a	50.5a
Cold Lake	Freshwater	5	150-225	101a	7.09a	9.10a	213a	160a	36.3a	16.0a	894a	150a	3.56a	1690a	52.3a
Rocky Mtn.	Freshwater	4	0-50	54.8a	2.76a	9.03a	341a	307a	33.7a	0.56a	87.0a	7.49a	1.62a	731a	10.1a
Rocky Mtn.	Freshwater	1	50-125	52.0a	2.75a	8.86a	369a	345a	23.5a	0.36a	88.0a	4.64a	1.27a	718a	8.90a
Rocky Mtn.	Freshwater	1	125-200	42.5a	2.67a	9.21a	455a	394a	60.1a	0.81a	43.0a	4.24a	3.98a	721a	14.6a
Rocky Mtn.	Water-N.A.	3	0-50	55.7a	6.68a	7.58a	88.7a	88.3a	0.32a	0.02a	2030a	1160a	115a	460a	160a
Rocky Mtn.	Water-N.A.	3	50-100	57.0a	7.39a	7.74a	86.3a	85.8a	0.50a	0.03a	2200a	1110a	107a	550a	138a
Waterton	Freshwater	5	0-100	297a	10.1a	9.80a	2010a	913a	1090a	4.64a	1030a	6.29a	0.77a	2840a	96.9a
Waterton	Freshwater	5	100-225	259a	8.85a	9.89a	1500a	758a	742a	4.17a	940a	5.11a	0.34a	2330a	114a
Waterton	Freshwater	5	225-350	190a	5.60a	9.55a	641a	413a	226a	2.45a	691a	16.9a	0.94a	1420a	83.4a
G.Prairie1	Freshwater	5	0-75	156a	17.4a	8.39a	288a	266a	21.8a	0.48a	296a	221a	11.6a	6710a	47.5a
G.Prairie1	Freshwater	5	75-150	143a	10.1A	9.43Aa	312a	192a	64.5a	55.43a	236a	149a	9.41a	2860a	31.7a
G.Prairie1	Freshwater	5	150-225	119a	10.8A	8.70a	210a	186a	22.6a	2.05a	382a	363a	11.0a	3370a	45.3a
G.Prairie2	Freshwater	4	0-30	85.4a	6.02a	8.57a	184a	174a	9.30a	0.33a	410a	370a	14.8a	1450a	32.5a
G.Prairie2	Freshwater	4	30-75	62.1a	7.28a	8.22a	306a	299a	6.53a	0.25a	249a	440a	39.9a	2010a	44.5a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
• Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Sr	S	Al	Cr	Fe	V	Ti	Cu (mg/L)	Pb	Zn	Mn	Li	B	Ba	P
Cold Lake	2.03a	1030a	1.38a	0.058a	0.052a	0.019a	0.006a	0.016a	0.01a	0.20a	0.013a	0.066a	1.16a	0.27a	0.13a
Cold Lake	0.93a	979a	0.86a	0.097a	0.002a	0.112a	0.002a	0.030a	0.01a	0.17a	0.007a	0.028a	1.26a	0.05a	0.15a
Cold Lake	1.18a	1180a	0.92a	0.037a	0.041a	0.041a	0.002a	0.015a	0.01a	0.19a	0.014a	0.079a	1.46a	0.06a	0.13a
Rocky Mtn.	0.14a	398a	2.35a	0.02b	0.67a	0.03b	0.05b	0.01b	0.10b	0.13a	0.01b	0.01a	0.13a	0.05b	0.57a
Rocky Mtn.	0.12a	379a	0.79a	0.02b	0.21a	0.03b	0.01b	0.01b	0.10b	0.14a	0.01b	0.04a	0.16a	0.01b	0.54a
Rocky Mtn.	0.15a	362a	21.0a	0.06a	9.77a	0.05a	0.61a	0.02a	0.11a	0.26a	0.07a	0.04a	0.21a	0.45a	0.97a
Rocky Mtn.	13.7a	529a	3.72a	0.02a	0.02a	0.03a	0.04a	0.02a	0.10a	0.14a	0.05a	1.06a	0.46a	0.08a	0.10a
Rocky Mtn.	14.5a	593a	3.73a	0.02a	0.02a	0.03a	0.04a	0.02a	0.10a	0.13a	0.04a	0.60a	0.30a	0.09a	0.13a
Waterton	0.38a	1180a	1.48a	0.96a	0.87a	0.11a	0.03a	0.05a	0.10a	0.38a	0.01a	0.04a	0.45a	0.03a	1.67a
Waterton	0.23a	1000a	0.28a	0.56a	0.26a	0.11a	0.01a	0.06a	0.33a	0.32a	0.01a	0.04a	0.33a	0.01a	1.22a
Waterton	0.38a	643a	0.88a	0.08a	0.29a	0.04a	0.01a	0.03a	0.10a	0.19a	0.01a	0.04a	0.21a	0.02a	0.63a
G.Prairie1	4.06a	4660a	1.49a	0.08a	0.07a	0.05a	0.01a	0.02a	0.10a	0.51a	0.07a	0.05a	1.02a	0.07a	0.41a
G.Prairie1	2.31a	1950a	1.18a	0.05a	0.04a	0.04a	0.01a	0.02a	0.10a	0.33a	0.04a	0.06a	0.59a	0.07a	0.25a
G.Prairie1	3.31a	2480a	1.88a	0.02a	0.03a	0.03a	0.02a	0.02a	0.10a	0.30a	0.04a	0.06a	0.79a	0.12a	0.19a
G Prairie2	1.79a	1640a	1.70a	0.02a	0.01a	0.03a	0.02a	0.01a	0.10a	0.12a	0.05a	0.08a	1.46a	0.21a	0.78a
G Prairie2	2.93a	1830a	1.90a	0.02a	0.01a	0.03a	0.02a	0.01a	0.10a	0.27a	0.77a	0.18a	0.76a	0.24a	0.21a

Concluded. Comparison of the mean values by depth of the saturated paste extract data for the freshwater gel solid phase samples.

Location	Waste	N	Depth (cm)	P	Mo	Ni	Co	Se	Si	As
				(mg/L)						
Cold Lake	Freshwater	5	0–75	0.13a*	1.12a	0.003a	0.001a	0.03a	10.2a	0.09a
Cold Lake	Freshwater	5	75–150	0.15a	1.41a	0.003a	0.001a	0.04a	20.7a	0.15a
Cold Lake	Freshwater	5	150–225	0.13a	1.61a	0.003a	0.001a	0.04a	13.2a	0.12a
Rocky Mtn.	Freshwater	4	0–50	0.57a	0.82a	0.03a	0.01a	0.30a	7.57b	0.13a
Rocky Mtn.	Freshwater	1	50–125	0.54a	0.79a	0.03a	0.01a	0.30a	4.14b	0.13a
Rocky Mtn.	Freshwater	1	125–200	0.97a	0.82a	0.03a	0.01a	0.30a	71.6a	0.20a
Rocky Mtn.	Water–N.A.	3	0–50	0.10a	0.05a	0.03a	0.01a	0.30a	11.1a	0.03a
Rocky Mtn.	Water–N.A.	3	50–100	0.13a	0.13a	0.03a	0.01a	0.30a	17.0a	0.03a
Waterton	Freshwater	5	0–100	1.67a	1.22a	0.03a	0.01a	0.43a	8.97a	0.57a
Waterton	Freshwater	5	100–225	1.22a	1.31a	0.03a	0.01a	0.34a	6.38a	0.52a
Waterton	Freshwater	5	225–350	0.63a	1.61a	0.03a	0.01a	0.30a	6.89a	0.27a
G.Prairie1	Freshwater	5	0–75	0.41a	1.10a	0.03a	0.01a	0.30a	14.9a	0.13a
G.Prairie1	Freshwater	5	75–150	0.25a	1.01a	0.03a	0.01a	0.30a	12.2a	0.09a
G.Prairie1	Freshwater	5	150–225	0.19a	0.70a	0.03a	0.01a	0.30a	10.7a	0.09a
G.Prairie2	Freshwater	4	0–30	0.78a	0.45a	0.03a	0.03a	0.30a	13.5a	0.11a
G.Prairie2	Freshwater	4	30–75	0.21a	0.29a	0.12a	0.02a	0.30a	6.26a	0.23a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by depth of the saturated paste extract data for the invert solid phase samples.

Location	N	Depth	Sat'n	E.C.	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S
		(cm)	(%)	(dS/m)		(mg/L)										
Rocky Mtn.	6	0-50	41.7a*	44.9a	7.65a	257a	256a	1.19a	0.02ab	21700a	8360a	162a	3100a	356a	119a	253a
Rocky Mtn.	2	50-100	42.8a	41.6a	8.17a	274a	270a	3.77a	0.07a	19600a	7510a	118a	2830a	369a	106a	225a
Rocky Mtn.	1	100-150	37.0a	42.3a	7.45a	237a	236a	0.62a	0.101b	23900a	9050a	142a	3530a	381a	142a	231a
G.Prairie	6	0-50	42.7a	39.0a	8.91a	310a	276a	33.2a	0.76a	19800a	9010a	8.74a	3690a	258a	66.3a	388a
G.Prairie	5	50-125	41.9a	38.8a	8.67a	295a	271a	22.9a	0.46a	19500a	7690a	10.9a	3390a	258a	59.3a	465a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo	Ni	Co
	(mg/L)															
Rocky Mtn.	17.6a	0.02a	0.03a	0.04a	0.10a	0.40a	0.12a	0.58a	0.12a	0.61a	0.42a	7.90a	0.61a	0.12a	0.24a	0.05a
Rocky Mtn.	16.4a	0.02a	0.03a	0.04a	0.09a	0.36a	0.19a	0.53a	0.04a	0.49a	0.32a	1.79a	0.60a	0.16a	0.19a	0.04a
Rocky Mtn.	17.9a	0.02a	0.04a	0.06a	0.10a	0.39a	0.13a	0.46a	0.11a	0.50a	0.31a	2.37a	0.72a	0.10a	0.19a	0.05a
G.Prairie	15.8a	0.02a	0.03a	0.15a	0.14a	0.14a	0.15a	0.37a	0.01a	0.25a	0.91a	2.44a	0.35a	0.55a	0.07a	0.03a
G.Prairie	15.8a	0.02a	0.01a	0.06a	0.14a	0.15a	0.16a	0.38a	0.03a	0.33a	1.22a	2.45a	0.33a	0.53a	0.08a	0.02a

Location	Se	Si	As
	(mg/L)		
Rocky Mtn.	0.30a	2.49a	0.16a
Rocky Mtn.	0.30a	2.32a	0.16a
Rocky Mtn.	0.30a	2.49a	0.17a
G.Prairie	0.30a	0.77a	0.24a
G.Prairie	0.30a	1.39a	0.25a

Comparison of the mean values by depth of the saturated paste extract data for the KCl solid phase samples.

Location	N	Depth	Sat'n	E.C.	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr
		(cm)	(%)	(dS/m)		(mg/L)									
Cold Lake	5	0–75	68.9a*	57.6a	8.47a	97.3a	92.7a	4.36a	0.28a	20800a	1280a	25.0a	5500a	15000a	12.1a
Cold Lake	5	75–150	64.4a	45.9a	8.76a	113a	87.8a	20.7a	4.18a	16400a	1020a	23.8a	4580a	11000a	8.78a
Cold Lake	4	150–225	69.1a	46.3a	8.71a	95.4a	74.2a	16.5a	4.75a	17600a	1170a	13.0a	4280a	11300a	9.76a
Waterton	5	0–75	63.0a	149a	7.85a	172a	170a	1.82a	0.05a	88800a	3480a	270a	13600a	56200a	82.6a
Waterton	5	75–175	69.0a	105b	8.23a	164a	160a	3.88a	0.12a	52900ab	2000a	115a	9750ab	36200b	46.3a
Waterton	5	175–275	64.6a	77.1b	8.44a	241a	233a	7.48a	0.16a	41300b	641a	114a	6800b	18400b	16.9a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg caCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	S	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo
	(mg/L)														
Cold Lake	2110a	3.53a	0.002a	0.10a	0.003a	0.001a	0.001a	0.01a	0.27a	0.10a	0.46a	0.99a	0.41a	0.02a	1.47a
Cold Lake	1510a	2.78a	0.035a	0.08a	0.003a	0.001a	0.011a	0.01a	0.22a	0.11a	0.37a	0.80a	0.43a	0.04a	1.51a
Cold Lake	1540a	3.37a	0.007a	0.02a	0.003a	0.001a	0.001a	0.01a	0.28a	0.02a	0.35a	0.87a	0.46a	0.02a	1.82a
Waterton	1780a	6.34a	0.02a	0.03a	0.03a	0.02a	0.12a	0.58a	3.41a	1.00a	3.70a	0.61a	0.14a	0.70a	0.55a
Waterton	1990a	5.30a	0.02a	0.01a	0.03a	0.02a	0.04a	0.25a	1.83a	0.29a	1.65a	0.16a	0.09a	0.70a	0.46a
Waterton	1900a	3.29a	0.03a	0.01a	0.03a	0.01a	0.03a	0.27a	1.95a	0.08a	0.67a	0.06a	0.03a	0.61a	0.58a

Location	Ni	Co	Se	Si	As
	(mg/L)				
Cold Lake	0.003a	0.001a	0.03a	4.47a	0.01a
Cold Lake	0.003a	0.001a	0.03a	4.83a	0.01a
Cold Lake	0.003a	0.001a	0.03a	5.45a	0.01a
Waterton	0.28a	0.05a	0.30a	1.62a	0.03a
Waterton	0.16a	0.01a	0.30a	5.82a	0.03a
Waterton	0.28a	0.01a	0.30a	5.21a	0.03a

Comparison of the mean values by depth of the saturated paste extract data for the NaCl solid phase samples.

Location	N	Depth (cm)	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr
											(mg/L)				
Cold Lake	5	0–75	70.9a*	153a	10.1a	290a	152a	102a	35.4a	95200a	1950a	10.4a	57600a	492a	3.44a
Cold Lake	5	75–150	54.6ab	154a	9.16a	333a	309a	18.9a	5.42a	99000a	2450a	14.1a	56700a	397a	6.19a
Cold Lake	5	150–225	52.2b	161a	8.59a	321a	316a	5.13a	0.41a	102000a	2130a	19.4a	59400a	404a	6.30a
Slave Lake	4	0–20	75.4a	16.1a	8.48a	505a	494a	10.4b	0.42a	6360a	1630a	94.7a	3150b	79.6a	7.46a
Slave Lake	1	0–50	75.5a	73.5a	7.80a	1700a	1690a	10.0a	0.03a	42300a	4720a	835a	4240b	243a	92.6a
Slave Lake	2	20–30	54.0a	35.2a	8.00a	232a	229a	2.84a	0.06a	16200a	2430a	180a	12300b	124a	14.1a
Slave Lake	1	20–50	70.0a	70.1a	9.00a	2050a	1870a	176a	0.50a	39200a	5490a	38.4a	41000a	204a	68.7a
Slave Lake	2	50–100	51.5a	104a	7.75a	64.6a	64.2a	0.33a	0.03a	73600a	6020a	645a	20300ab	376a	141a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	S	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo
								(mg/L)							
Cold Lake	1200a	4.81a	0.013a	0.001a	0.003a	0.001a	0.003a	0.01a	0.78a	0.001a	0.007a	0.06a	0.27a	0.11a	0.07a
Cold Lake	1150a	5.80a	0.002a	0.049a	0.003a	0.001a	0.001a	0.01a	0.98a	0.018a	0.004a	0.05a	0.37a	0.07a	0.10a
Cold Lake	1180a	4.99a	0.002a	0.087a	0.003a	0.001a	0.001a	0.01a	1.24a	0.038a	0.004a	0.11a	0.35a	0.07a	0.11a
Slave Lake	749a	4.47a	0.03a	0.01b	0.03a	0.04a	0.02b	0.10a	0.28a	0.12a	0.36a	1.02a	0.14a	0.20a	0.28a
Slave Lake	710a	9.30a	0.23a	0.13a	0.03a	0.05a	0.09b	0.10a	0.78a	0.48a	2.11a	1.22a	0.27a	1.27a	0.06a
Slave Lake	795a	6.17a	0.02b	0.01b	0.03a	0.04a	0.02b	0.10a	0.62a	0.16a	0.67a	1.22a	0.07a	0.46a	0.20a
Slave Lake	556a	10.6a	0.03b	0.02b	0.03a	0.07a	0.54a	0.10a	0.78a	0.02a	0.84a	0.49a	0.20a	0.85a	0.22a
Slave Lake	478a	9.92a	0.02b	0.02b	0.03a	0.05a	0.06b	0.10a	0.93a	0.16a	2.37a	1.40a	0.19a	1.42a	0.07a

Location	Ni	Co	Se	Si	As
			(mg/L)		
Cold Lake	0.003a	0.001a	0.03a	3.76a	0.003a
Cold Lake	0.003a	0.001a	0.03a	3.30a	0.003a
Cold Lake	0.003a	0.001a	0.03a	3.01a	0.003a
Slave Lake	0.03a	0.01a	0.30a	3.17a	0.09a
Slave Lake	0.03a	0.01a	0.30a	0.54a	0.21a
Slave Lake	0.12a	0.01a	0.30a	2.96a	0.07a
Slave Lake	0.03a	0.01a	0.30a	2.43a	0.17a
Slave Lake	0.03a	0.01a	0.30a	1.45a	0.11a

10.6 COMPARISON OF THE MEAN VALUES BY HORIZONTAL POSITION OF THE SATURATED PASTE EXTRACT DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by horizontal position of the saturated paste extract data for the DAP solid phase samples.

Location	N	Hole No.	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr
										(mg/L)					
Cold Lake	2	1	101a*	10.4ab	12.1ab	1300ab	5.06c	641ab	659a	2230a	600a	0.10a	965a	519a	3.80a
Cold Lake	3	2	95.5a	13.7a	12.3a	2200a	7.50c	1280a	911a	2220a	223a	0.10a	1310a	970a	2.12a
Cold Lake	3	3	97.5a	4.12cd	8.32c	261b	256b	5.0b	0.10b	201c	14.3a	5.25a	992a	49.2a	0.30a
Cold Lake	3	4	82.7a	8.98abc	11.4ab	666b	23.3c	509ab	133b	1700abc	125a	0.11a	737a	500a	0.63a
Cold Lake	3	5	79.33a	8.63bc	11.2b	766b	40.3c	635ab	90.4b	1340ab	154a	0.16a	696a	476a	0.60a
Cold Lake	3	6	84.5a	3.53d	8.76c	548b	513a	34.2b	0.37b	361bc	17.7a	3.32a	39.6a	43.8a	0.14a
Cold Lake	3	7	65.5a	3.28d	8.67c	483b	460ab	22.4b	0.28b	349bc	13.2a	3.37a	26.3a	30.4a	0.14a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg caCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	S	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo	Ni
								(mg/L)								
Cold Lake	65.0a	2.60a	0.09a	0.01a	0.03c	0.02a	0.01a	0.10a	0.12a	0.006a	0.08a	0.04b	0.75a	0.15a	0.12b	0.03a
Cold Lake	586a	1.62ab	0.10a	0.01a	0.03c	0.02a	0.03a	0.10a	0.22a	0.006a	0.05a	0.04b	0.30a	0.37a	0.19b	0.03a
Cold Lake	680a	0.23b	0.02a	0.01a	0.08bc	0.01a	0.01a	0.10a	0.14a	0.006a	0.19a	2.05a	0.02a	28.5a	2.07a	0.04a
Cold Lake	339a	1.37ab	0.22a	0.01a	0.03c	0.01a	0.02a	0.10a	0.14a	0.006a	0.04a	0.10b	0.05a	0.26a	0.42b	0.03a
Cold Lake	401a	1.51ab	0.20a	0.01a	0.03c	0.01a	0.02a	0.10a	0.15a	0.006a	0.04a	0.08b	0.04a	0.22a	0.16b	0.03a
Cold Lake	362a	0.21b	0.03a	0.08a	0.23a	0.01a	0.02a	0.10a	0.11a	0.007a	0.13a	2.32a	0.01a	33.4a	0.94b	0.04a
Cold Lake	339a	0.24b	0.02a	0.08a	0.21ab	0.01a	0.02a	0.10a	0.12a	0.006a	0.13a	2.25a	0.01a	71.7a	0.92b	0.03a

Location	Co	Se	Si	As
		(mg/L)		
Cold Lake	0.01a	0.30a	6.05a	0.03b
Cold Lake	0.01a	0.30a	4.65a	0.03b
Cold Lake	0.01a	0.30a	4.28a	0.35ab
Cold Lake	0.01a	0.30a	14.9a	0.03b
Cold Lake	0.01a	0.30a	19.8a	0.03b
Cold Lake	0.01a	0.30a	12.0a	0.57a
Cold Lake	0.01a	0.30a	10.7a	0.66a

Comparison of the mean values by horizontal position of the saturated paste extract data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K
											(mg/L)				
Cold Lake	Freshwater	3	1	82.8a*	8.34a	10.5a	205a	42.9c	103a	58.4a	1280a	316a	3.78a	2050a	85.0a
Cold Lake	Freshwater	3	2	94.2a	9.14a	10.6a	699a	59.7bc	485a	154a	989a	322a	1.15a	1730a	142a
Cold Lake	Freshwater	3	3	94.8a	7.16a	9.7a	177a	78.7abc	89.9a	8.46a	948a	223a	2.19a	1770a	50.3a
Cold Lake	Freshwater	3	4	131a	6.68a	8.6a	249a	240a	8.8a	0.19a	1010a	56.2a	2.44a	1800a	43.1a
Cold Lake	Freshwater	3	5	130a	6.38a	8.5a	227a	220ab	6.9a	0.17a	996a	60.7a	2.85a	1690a	30.9a
Rocky Mtn.	Freshwater	3	18	47.7a	2.75a	9.08a	397a	354a	42.5a	0.63a	80a	6.10a	2.37a	750a	12.5a
Rocky Mtn.	Freshwater	1	19	49.0a	3.08a	8.84a	248a	232a	15.1a	0.35a	74a	11.7a	2.21a	799a	9.61a
Rocky Mtn.	Freshwater	1	20	59.5a	2.59a	9.16a	412a	362a	49.2a	0.72a	48a	4.70a	0.98a	672a	7.49a
Rocky Mtn.	Freshwater	1	21	62.0a	2.53a	8.96a	336a	309a	42.5a	0.46a	117a	4.12a	1.44a	645a	9.20a
Rocky Mtn.	Water-N.A.	2	6	57.3a	7.42a	7.61a	83.0a	82.7a	0.31a	0.02a	2380a	1250a	132a	502a	150a
Rocky Mtn.	Water-N.A.	2	7	57.0a	7.12a	7.78a	95.0a	94.4a	0.59a	0.03a	1960a	962a	84.4a	618a	201a
Rocky Mtn.	Water-N.A.	2	8	54.8a	6.58a	7.60a	84.5a	84.2a	0.31a	0.02a	2010a	1190a	117a	393a	96.1a
Waterton	Freshwater	3	1	265a	4.91a	9.68a	449a	308a	139a	2.40a	1020a	3.01a	0.60a	1180a	97.0a
Waterton	Freshwater	3	2	292a	5.37a	9.43a	388a	276a	110a	1.78a	987a	10.6a	1.28a	1240a	70.0a
Waterton	Freshwater	3	3	293a	10.2a	10.1a	2260a	1060a	1200a	6.11a	462a	2.96a	0.24a	2730a	67.3a
Waterton	Freshwater	3	4	191a	10.1a	9.90a	2200a	1020a	1180a	4.89a	583a	3.86a	0.21a	2810a	108a
Waterton	Freshwater	3	5	203a	10.4a	9.64a	1630a	820a	804a	3.58a	1370a	26.8a	1.10a	3020a	148a
G. Prairie1	Freshwater	3	3	99.8a	11.1a	8.26a	259a	244a	14.5a	0.33a	270ab	242a	5.03b	2730a	47.8a
G. Prairie1	Freshwater	3	7	118a	5.38a	8.99a	225a	186a	35.8a	3.34a	308ab	218a	5.87b	1380a	28.8a
G. Prairie1	Freshwater	3	8	181a	5.20a	9.99a	317a	133a	91.5a	92.1a	664a	109a	0.86b	1280a	18.8a
G. Prairie1	Freshwater	3	9	137a	19.6a	8.81a	292a	266a	25.5a	0.47a	161b	285a	9.74b	7540a	52.9a
G. Prairie1	Freshwater	3	10	160a	22.6a	8.16a	259a	244a	14.3a	0.42a	122b	366a	31.8a	8650a	59.0a
G. Prairie2	Freshwater	2	6	73.5a	6.35a	8.30a	160a	153a	5.74a	0.32a	356a	631a	26.5a	1370a	43.9a
G. Prairie2	Freshwater	2	7	88.5a	5.89a	8.96a	164a	151a	12.0a	0.48a	608a	506a	8.24a	1310a	31.7a
G. Prairie2	Freshwater	2	8	71.0a	7.48a	8.31a	254a	248a	5.84a	0.16a	232a	175a	12.9a	2290a	36.2a
G. Prairie2	Freshwater	2	9	62.0a	6.89a	8.00a	403a	395a	8.12a	0.20a	122a	307a	61.7a	1950a	42.0a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Continued. Comparison of the mean values by horizontal position of the saturated paste extract data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Sr	S	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn
				(mg/L)										
Cold Lake	Freshwater	3	1	1.49a*	1470a	1.59a	0.15a	0.08a	0.05a	0.004a	0.04a	0.01a	0.21a	0.010a
Cold Lake	Freshwater	3	2	1.45a	1010a	1.40a	0.06a	0.02a	0.05a	0.003a	0.02a	0.01a	0.18a	0.002a
Cold Lake	Freshwater	3	3	1.06a	1330a	1.21a	0.08a	0.03a	0.15a	0.004a	0.03a	0.01a	0.18a	0.007a
Cold Lake	Freshwater	3	4	1.31a	808a	0.50a	0.02a	0.03a	0.02a	0.003a	0.01a	0.01a	0.19a	0.020a
Cold Lake	Freshwater	3	5	1.59a	797a	0.57a	0.01a	0.00a	0.01a	0.002a	0.01a	0.01a	0.19a	0.018a
Rocky Mtn.	Freshwater	3	18	0.15a	392a	8.04a	0.03a	3.54a	0.04a	0.22a	0.02a	0.10a	0.18a	0.03a
Rocky Mtn.	Freshwater	1	19	0.20a	489a	0.20a	0.02a	0.30a	0.03a	0.01a	0.01a	0.10a	0.10a	0.01a
Rocky Mtn.	Freshwater	1	20	0.07a	348a	0.20a	0.02a	0.01a	0.03a	0.01a	0.01a	0.10a	0.09a	0.01a
Rocky Mtn.	Freshwater	1	21	0.11a	318a	6.67a	0.02a	1.99a	0.03a	0.13a	0.01a	0.10a	0.19a	0.02a
Rocky Mtn.	Water-N.A.	2	6	17.3a	510a	3.92a	0.02a	0.02a	0.03a	0.04a	0.01a	0.10a	0.14a	0.06a
Rocky Mtn.	Water-N.A.	2	7	9.78a	656a	3.38a	0.02a	0.02a	0.03a	0.04a	0.02a	0.10a	0.16a	0.04a
Rocky Mtn.	Water-N.A.	2	8	15.2a	519a	3.89a	0.02a	0.02a	0.03a	0.04a	0.03a	0.10a	0.12a	0.04a
Waterton	Freshwater	3	1	0.19a	371a	2.53a	0.08a	0.89a	0.03a	0.04a	0.03a	0.10a	0.16a	0.01a
Waterton	Freshwater	3	2	0.50a	457a	0.90a	0.03a	0.28a	0.04a	0.01a	0.03a	0.10a	0.21a	0.01a
Waterton	Freshwater	3	3	0.18a	1310a	0.36a	0.32a	0.19a	0.10a	0.01a	0.06a	0.48a	0.37a	0.01a
Waterton	Freshwater	3	4	0.19a	1340a	0.26a	1.40a	0.62a	0.15a	0.01a	0.05a	0.10a	0.39a	0.01a
Waterton	Freshwater	3	5	0.60a	1230a	0.36a	0.84a	0.39a	0.12a	0.01a	0.05a	0.10a	0.33a	0.01a
G. Prairie1	Freshwater	3	3	2.65ab	1910a	1.51a	0.07a	0.03a	0.05a	0.02a	0.03a	0.10a	0.36ab	0.01a
G. Prairie1	Freshwater	3	7	1.05b	1300a	1.17a	0.02a	0.03a	0.04a	0.02a	0.04a	0.10a	0.14b	0.05a
G. Prairie1	Freshwater	3	8	0.95b	1911a	0.88a	0.02a	0.01a	0.05a	0.01a	0.01a	0.10a	0.13b	0.02a
G. Prairie1	Freshwater	3	9	5.23ab	5100a	1.79a	0.10a	0.05a	0.03a	0.01a	0.01a	0.10a	0.59ab	0.07a
G. Prairie1	Freshwater	3	10	6.24a	6180a	2.25a	0.05a	0.09a	0.03a	0.02a	0.01a	0.10a	0.66a	0.09a
G. Prairie2	Freshwater	2	6	2.63a	1830a	2.51a	0.02a	0.01a	0.03a	0.04a	0.01a	0.10a	0.15a	0.06a
G. Prairie2	Freshwater	2	7	2.37a	1620a	2.14a	0.02a	0.01a	0.03a	0.03a	0.01a	0.10a	0.14a	0.09a
G. Prairie2	Freshwater	2	8	2.36a	1810a	1.06a	0.02a	0.01a	0.03a	0.01a	0.01a	0.10a	0.19a	0.14a
G. Prairie2	Freshwater	2	9	2.09a	1680a	1.49a	0.02a	0.01a	0.03a	0.10a	0.01a	0.10a	0.30a	1.43a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Concluded. Comparison of the mean values by horizontal position of the saturated paste extract data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Li	B	Ba	P	Mo	Ni	Co	Se	Si	As
				(mg/L)									
Cold Lake	Freshwater	3	1	0.04a*	0.33c	0.06a	0.14a	1.53a	0.003a	0.001a	0.03a	20.3a	0.07a
Cold Lake	Freshwater	3	2	0.02a	0.44c	0.18a	0.15a	1.24a	0.003a	0.001a	0.03a	13.0a	0.07a
Cold Lake	Freshwater	3	3	0.03a	0.92bc	0.06a	0.13a	1.51a	0.003a	0.001a	0.03a	23.6a	0.11a
Cold Lake	Freshwater	3	4	0.09a	2.59a	0.07a	0.14a	1.41a	0.003a	0.001a	0.05a	8.67a	0.18a
Cold Lake	Freshwater	3	5	0.11a	2.17ab	0.28a	0.11a	1.21a	0.003a	0.001a	0.04a	7.93a	0.17a
Rocky Mtn.	Freshwater	3	18	0.04a	0.18a	0.17a	0.62a	0.76a	0.03a	0.01a	0.300b	27.7a	0.15a
Rocky Mtn.	Freshwater	1	19	0.04a	0.09a	0.06a	0.40a	0.58a	0.03a	0.01a	0.301a	4.43a	0.08a
Rocky Mtn.	Freshwater	1	20	0.04a	0.15a	0.01a	0.57a	0.81a	0.03a	0.01a	0.300b	2.11a	0.17a
Rocky Mtn.	Freshwater	1	21	0.04a	0.12a	0.08a	0.95a	1.22a	0.03a	0.01a	0.300b	16.4a	0.15a
Rocky Mtn.	Water-N.A.	2	6	1.01a	0.46a	0.06a	0.11a	0.06a	0.03a	0.01a	0.30a	10.7a	0.03a
Rocky Mtn.	Water-N.A.	2	7	0.71a	0.34a	0.08a	0.12a	0.12a	0.03a	0.01a	0.30a	15.9a	0.03a
Rocky Mtn.	Water-N.A.	2	8	0.77a	0.35a	0.11a	0.12a	0.10a	0.03a	0.01a	0.30a	15.6a	0.03a
Waterton	Freshwater	3	1	0.04a	0.14a	0.04a	0.43a	1.26a	0.03a	0.01a	0.30a	7.52a	0.21a
Waterton	Freshwater	3	2	0.04a	0.23a	0.02a	0.62a	1.22a	0.03a	0.01a	0.30a	3.54a	0.18a
Waterton	Freshwater	3	3	0.04a	0.40a	0.01a	1.90a	1.45a	0.03a	0.01a	0.30a	5.74a	0.79a
Waterton	Freshwater	3	4	0.04a	0.51a	0.01a	1.66a	1.74a	0.03a	0.01a	0.44a	9.77a	0.63a
Waterton	Freshwater	3	5	0.04a	0.37a	0.01a	1.24a	1.23a	0.03a	0.01a	0.44a	10.5a	0.45a
G. Prairie1	Freshwater	3	3	0.07a	0.89a	0.05a	0.12a	1.24a	0.03a	0.01a	0.30a	14.2a	0.08ab
G. Prairie1	Freshwater	3	7	0.04a	0.70a	0.11a	0.34a	0.64a	0.03a	0.01a	0.30a	11.5a	0.09ab
G. Prairie1	Freshwater	3	8	0.05a	0.85a	0.19a	0.44a	0.35a	0.03a	0.01a	0.30a	29.6a	0.23a
G. Prairie1	Freshwater	3	9	0.04a	0.85a	0.04a	0.34a	1.35a	0.03a	0.01a	0.30a	5.78a	0.08ab
G. Prairie1	Freshwater	3	10	0.09a	0.71a	0.03a	0.17a	1.11a	0.03a	0.01a	0.30a	1.80a	0.05b
G. Prairie2	Freshwater	2	6	0.11a	1.03a	0.22a	0.99a	0.49a	0.03a	0.01b	0.30a	10.8a	0.09a
G. Prairie2	Freshwater	2	7	0.04a	0.88a	0.49a	0.25a	0.50a	0.03a	0.01b	0.30a	8.77a	0.10a
G. Prairie2	Freshwater	2	8	0.09a	1.31a	0.06a	0.14a	0.26a	0.03a	0.01b	0.30a	10.0a	0.21a
G. Prairie2	Freshwater	2	9	0.26a	1.22a	0.14a	0.62a	0.24a	0.22a	0.07a	0.30a	9.97a	0.29a

Comparison of the mean values by horizontal position of the saturated paste extract data for the invert solid phase samples.

Location	N	Hole No.	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S
											(mg/L)					
Rocky Mtn.	2	12	42.0a*	43.7a	7.76a	280a	278a	1.91a	0.04a	20100a	8120a	167a	2880a	352a	109a	322a
Rocky Mtn.	1	13	37.0a	49.6a	7.46a	277a	276a	0.75a	0.01a	24800a	9430a	166a	3440a	383a	139a	264a
Rocky Mtn.	1	14	47.5a	41.9a	7.85a	279a	277a	1.84a	0.04a	19700a	8180a	149a	2570a	288a	103a	333a
Rocky Mtn.	3	15	41.8a	40.8a	7.81a	263a	261a	2.15a	0.04a	20733a	7650a	128a	3070a	372a	118a	184a
Rocky Mtn.	1	16	40.5a	43.3a	7.90a	262a	260a	1.94a	0.04a	21400a	8610a	121a	2620a	354a	94a	297a
Rocky Mtn.	1	17	38.0a	50.2a	7.54a	160a	159a	0.52a	0.02a	24800a	8790a	194a	4200a	410a	162a	111a
G. Prairie	1	6	53.5a	42.5a	9.71a	283a	189a	91.2a	2.56a	21300a	9780a	2.68a	3330a	262a	102a	196a
G. Prairie	2	7	39.8a	39.9a	9.14a	316a	276a	38.6a	0.73a	21200a	10100a	7.55a	3670a	279a	86.8a	274a
G. Prairie	2	8	40.8a	35.8a	8.36a	357a	345a	10.9a	0.18a	17900a	7120a	13.4a	3460a	240a	46.6a	549a
G. Prairie	2	9	43.5a	39.1a	8.94a	247a	226a	26.7a	0.50a	18000a	7510a	9.78a	3710a	227a	47.8a	510a
G. Prairie	2	10	41.0a	38.1a	8.34a	325a	301a	23.9a	0.38a	20600a	8020a	12.5a	3320a	275a	55:6a	435a
G. Prairie	2	11	41.3a	39.9a	8.80a	281a	263a	17.1a	0.36a	19900a	8620a	8.74a	3730a	267a	59.7a	461a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio; * Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo	Ni	Co
									(mg/L)							
Rocky Mtn.	17.2a	0.02a	0.02a	0.04a	0.09a	0.34a	0.10a	0.49a	0.15a	0.58a	0.39a	1.19b	0.50a	0.11a	0.25a	0.05a
Rocky Mtn.	19.2a	0.02a	0.03a	0.04a	0.10a	0.38a	0.13a	0.63a	0.13a	0.64a	0.45a	1.84b	0.73a	0.11a	0.22a	0.05a
Rocky Mtn.	17.4a	0.02a	0.02a	0.03a	0.09a	0.33a	0.10a	0.73a	0.12a	0.52a	0.47a	1.26b	0.47a	0.20a	0.37a	0.07a
Rocky Mtn.	16.4a	0.02a	0.03a	0.05a	0.09a	0.42a	0.17a	0.51a	0.07a	0.47a	0.19a	3.78b	0.70a	0.12a	0.17a	0.08a
Rocky Mtn.	18.1a	0.02a	0.04a	0.06a	0.11a	0.38a	0.15a	0.72a	0.06a	0.63a	0.40a	0.71b	0.70a	0.18a	0.27a	0.05a
Rocky Mtn.	18.0a	0.02a	0.04a	0.05a	0.10a	0.42a	0.12a	0.46a	0.07a	0.79a	0.51a	35.9a	0.57a	0.05a	0.12a	0.03a
G. Prairie	17.6a	0.02a	0.01a	0.08a	0.15a	0.18a	0.20a	0.31a	0.01a	0.12a	0.91a	5.34a	0.30a	0.41a	0.08a	0.04a
G. Prairie	16.6a	0.02a	0.06a	0.32a	0.14a	0.16a	0.17a	0.35a	0.01a	0.19a	0.83a	4.42a	0.35a	0.47a	0.07a	0.03a
G. Prairie	15.0a	0.02a	0.01a	0.06a	0.13a	0.15a	0.15a	0.42a	0.04a	0.30a	1.38a	1.20a	0.32a	0.74a	0.08a	0.02a
G. Prairie	14.2a	0.02a	0.01a	0.06a	0.13a	0.12a	0.14a	0.35a	0.01a	0.38a	0.87a	1.30a	0.34a	0.54a	0.07a	0.03a
G. Prairie	16.3a	0.02a	0.01a	0.06a	0.14a	0.15a	0.15a	0.44a	0.04a	0.33a	1.17a	2.27a	0.36a	0.51a	0.08a	0.03a
G. Prairie	15.8a	0.02a	0.02a	0.05a	0.14a	0.14a	0.15a	0.35a	0.01a	0.33a	1.09a	1.58a	0.35a	0.53a	0.08a	0.02a

Location	Se	Si	As
		(mg/L)	
Rocky Mtn.	0.30a	2.50a	0.19a
Rocky Mtn.	0.30a	2.52a	0.16a
Rocky Mtn.	0.30a	2.67a	0.18a
Rocky Mtn.	0.30a	2.49a	0.15a
Rocky Mtn.	0.30a	2.27a	0.16a
Rocky Mtn.	0.30a	2.16a	0.13a
G. Prairie	0.30a	1.08a	0.28a
G. Prairie	0.30a	0.68a	0.26a
G. Prairie	0.30a	1.56a	0.24a
G. Prairie	0.30a	0.69a	0.22a
G. Prairie	0.30a	1.40a	0.25a
G. Prairie	0.30a	0.90a	0.25a

Comparison of the mean values by horizontal position of the saturated paste extract data for the KCl solid phase samples.

Location	N	Hole No.	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S
						(mg/L)										
Cold Lake	3	1	60.3a*	47.5a	7.3a	111a	111a	0.2a	0.01a	16200a	930a	46.2a	4670a	11700a	16.1a	1940a
Cold Lake	3	2	65.2a	38.6a	8.8a	79.7a	73.9a	5.4a	0.38a	13200a	1310a	15.5a	4340a	8240a	5.01a	1730a
Cold Lake	3	3	69.7a	51.1a	9.5a	108a	65.9a	35.4a	6.98a	19700a	1300a	5.47a	5020a	12900a	5.01a	1890a
Cold Lake	3	4	73.8a	47.1a	9.4a	84.2a	54.9a	22.9a	6.44a	16600a	1600a	11.2a	4270a	11200a	9.46a	1650a
Cold Lake	3	5	67.0a	62.7a	8.2a	120a	119a	1.6a	0.07a	24000a	686a	25.4a	5640a	17100a	13.9a	1440a
Waterton	3	1	64.7a	101a	8.36a	193a	188a	4.17a	0.12a	43900a	505a	24.8a	6760a	37400a	16.5a	2480a
Waterton	3	2	61.7a	111a	8.28a	198a	193a	4.09a	0.11a	58100a	844a	61.0a	11400a	41500a	13.2a	2150a
Waterton	3	3	69.0a	110a	8.42a	235a	224a	10.2a	0.22a	74100a	2770a	305a	11400a	36000a	52.5a	2110a
Waterton	3	4	59.5a	126a	7.80a	171a	170a	1.39a	0.04a	74600a	5060a	263a	11600a	41800a	124a	1400a
Waterton	3	5	73.3a	106a	8.02a	164a	162a	2.11a	0.07a	54400a	1030a	177a	9030a	27900a	36.8a	1300a

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg CaCO3/ L); SAR = Sodium Adsorption Ratio;
* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo
	(mg/L)													
Cold Lake	2.64ab	0.002a	0.02a	0.003a	0.001a	0.001a	0.01a	0.412a	0.199a	0.71a	1.18ab	0.46ab	0.01a	1.42a
Cold Lake	3.85ab	0.002a	0.18a	0.003a	0.001a	0.001a	0.01a	0.170a	0.155a	0.18bc	0.68ab	0.32b	0.02a	1.95a
Cold Lake	3.59ab	0.057a	0.01a	0.003a	0.001a	0.017a	0.01a	0.241a	0.001a	0.13c	0.40a	0.36b	0.06a	1.84a
Cold Lake	4.43a	0.009a	0.08a	0.003a	0.001a	0.001a	0.01a	0.002a	0.008a	0.21abc	0.34a	0.36b	0.02a	1.33a
Cold Lake	1.78b	0.002a	0.10a	0.003a	0.001a	0.001a	0.01a	0.434a	0.056a	0.69ab	1.76a	0.60a	0.01a	1.53a
Waterton	1.77a	0.02a	0.01a	0.03a	0.01a	0.03a	0.10a	0.74a	0.02a	0.37a	0.04a	0.06a	0.37a	0.45a
Waterton	2.96a	0.02a	0.01a	0.03a	0.01a	0.02a	0.18a	1.08a	0.09a	0.84a	0.05a	0.06a	0.73a	0.59a
Waterton	5.41a	0.03a	0.02a	0.03a	0.02a	0.13a	0.55a	3.65a	0.65a	2.92a	0.68a	0.04a	0.82a	0.58a
Waterton	8.94a	0.02a	0.02a	0.03a	0.03a	0.11a	0.87a	4.95a	1.05a	4.53a	0.54a	0.19a	0.82a	0.50a
Waterton	5.81a	0.02a	0.02a	0.03a	0.02a	0.03a	0.14a	1.59a	0.47a	1.37a	0.07a	0.09a	0.60a	0.51a

Location	Ni	Co	Se	Si	As
	(mg/L)				
Cold Lake	0.003a	0.001a	0.03a	4.12a	0.003a
Cold Lake	0.003a	0.001a	0.03a	6.77a	0.009a
Cold Lake	0.003a	0.001a	0.03a	5.47a	0.015a
Cold Lake	0.003a	0.001a	0.03a	5.25a	0.014a
Cold Lake	0.003a	0.001a	0.03a	3.43a	0.005a
Waterton	0.03a	0.01a	0.30a	4.01a	0.03a
Waterton	0.19a	0.01a	0.30a	7.41a	0.03a
Waterton	0.42a	0.05a	0.30a	4.47a	0.03a
Waterton	0.41a	0.03a	0.30a	1.47a	0.03a
Waterton	0.14a	0.01a	0.30a	3.72a	0.03a

Comparison of the mean values by horizontal position of the saturated paste extract data for the NaCl solid phase samples.

Location	N	Hole No.	Sat'n (%)	E.C. (dS/m)	pH	Alk.	HCO3	CO3	OH	Cl	Ca	Mg	Na	K	Sr	S
						(mg/L)										
Cold Lake	3	1	53.3a*	110a	9.4a	173b	66.1a	79.1a	27.8a	58000a	2180a	8.82a	35300a	365a	6.01a	759a
Cold Lake	2	2	51.8a	187a	10.5a	119b	6.4a	74.1a	38.7a	123000a	2090a	0.01a	73000a	553a	4.97a	915a
Cold Lake	3	3	65.8a	177a	9.2a	169b	146a	21.8a	1.60a	125000a	2460a	10.4a	69200a	518a	3.99a	1420a
Cold Lake	3	4	61.7a	137a	8.5a	985a	959a	26.1a	0.18a	79100a	2000a	34.1a	46300a	325a	7.33a	1090a
Cold Lake	3	5	63.5a	168a	8.9a	127b	118a	9.42a	0.40a	108000a	2210a	12.5a	65700a	394a	4.25a	1690a
Slave Lake	2	1	70.5a	45.7a	8.48a	368a	355a	12.5a	0.18a	22300a	3620a	118ab	10700a	144a	16.7a	650a
Slave Lake	2	2	68.0a	12.6a	8.61a	90.0a	83.9a	5.39a	0.67a	4140a	1170a	88.5b	6370a	99.2a	5.32a	943a
Slave Lake	2	3	64.5a	99.1a	7.80a	869a	864a	5.13a	0.03a	70100a	5890a	897a	12400a	364a	150a	548a
Slave Lake	3	4	59.3a	55.6a	8.20a	1200a	1140a	62.5a	0.19a	30800a	4000a	216ab	21000a	172a	51.5a	645a
Slave Lake	1	5	74.0a	4.83a	7.85a	109a	108a	0.72a	0.04a	877a	300a	50.3b	895a	35.8a	3.12a	594a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Al	Cr	Fe	V	Ti	Cu	Pb	Zn	Mn	Li	B	Ba	P	Mo
	(mg/L)													
Cold Lake	5.28a	0.021a	0.011a	0.003a	0.001a	0.001a	0.01a	0.66a	0.001a	0.004a	0.04b	0.56a	0.05b	0.12a
Cold Lake	4.90a	0.002a	0.001a	0.003a	0.001a	0.001a	0.01a	0.46a	0.001a	0.004a	0.02b	0.26a	0.01b	0.16a
Cold Lake	5.52a	0.002a	0.016a	0.003a	0.001a	0.001a	0.01a	1.33a	0.005a	0.004a	0.01b	0.18a	0.02b	0.02a
Cold Lake	5.15a	0.002a	0.200a	0.003a	0.001a	0.001a	0.01a	1.24a	0.087a	0.004a	0.21a	0.47a	0.25a	0.10a
Cold Lake	5.16a	0.002a	0.001a	0.003a	0.001a	0.004a	0.01a	1.30a	0.001a	0.009a	0.09ab	0.19a	0.10ab	0.07a
Slave Lake	8.46a	0.02a	0.01a	0.03a	0.06a	0.04a	0.10a	0.70a	0.10a	0.65a	0.88a	0.17a	0.39a	0.27a
Slave Lake	3.74a	0.02a	0.01a	0.03a	0.04a	0.02a	0.10a	0.27a	0.08a	0.28a	0.93a	0.07a	0.16a	0.30a
Slave Lake	9.85a	0.12a	0.08a	0.03a	0.05a	0.08a	0.10a	0.88a	0.32a	2.63a	1.34a	0.21a	1.54a	0.05a
Slave Lake	8.14a	0.03a	0.02a	0.03a	0.06a	0.20a	0.10a	0.65a	0.14a	1.07a	1.02a	0.18a	0.80a	0.13a
Slave Lake	1.37a	0.02a	0.01a	0.03a	0.01a	0.01a	0.10a	0.13a	0.19a	0.16a	1.68a	0.14a	0.10a	0.30a

Location	Ni	Co	Se	Si	As
	(mg/L)				
Cold Lake	0.003a	0.001a	0.03a	4.61a	0.003a
Cold Lake	0.003a	0.001a	0.03a	3.26a	0.003a
Cold Lake	0.003a	0.001a	0.03a	2.55a	0.003a
Cold Lake	0.003a	0.001a	0.03a	2.95a	0.003a
Cold Lake	0.003a	0.001a	0.03a	3.41a	0.003a
Slave Lake	0.03a	0.01a	0.30a	2.91ab	0.11a
Slave Lake	0.12a	0.01a	0.30a	4.03a	0.06a
Slave Lake	0.03a	0.01a	0.30a	0.32b	0.16a
Slave Lake	0.03a	0.01a	0.30a	2.75ab	0.13a
Slave Lake	0.04a	0.01a	0.30a	1.71ab	0.06a

10.7 COMPARISON OF THE MEAN VALUES BY DEPTH OF THE DTPA EXTRACT DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by depth of the DTPA extract data for the DAP solid phase samples.

Location	N	Depth (cm)	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni	Se
										(ug/g)							
Cold Lake	7	0–30	116a*	0.25a	5.68a	13.1a	20.7a	13.8a	275a	97.7a	2440a	1670a	2.29a	117a	0.68a	1.93a	0.89a
Cold Lake	7	30–60	99a	0.25a	5.18a	15.5a	27.2a	11.8a	291a	115a	2150a	933a	2.00a	78.0a	0.64a	1.71a	0.82a
Cold Lake	6	60–90	119a	0.25a	4.23a	22.8a	29.5a	10.1a	290a	84.2a	1310a	477a	1.79a	86.0a	0.50a	1.46a	0.79a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by depth of the DTPA extract data for the freshwater gel solid phase samples.

Location	Waste	N	Depth (cm)	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P
				(ug/g)											
Cold Lake	Freshwater	5	0-75	164a*	0.16a	9.14a	18.6a	20.1a	20.6a	203a	102a	2170a	276a	3.50a	3.94a
Cold Lake	Freshwater	5	75-150	176a	0.14a	9.72a	13.6a	18.3a	19.7a	191a	93.7a	2050a	223a	3.38a	4.28a
Cold Lake	Freshwater	5	150-225	198a	0.10a	10.1a	11.4a	17.9a	19.9a	185a	112a	2100a	222a	3.64a	3.34a
Rocky Mtn.	Freshwater	4	0-50	90.1a	0.25a	5.81a	10.9a	25.4a	5.81a	299a	58.1a	1480a	165a	0.25a	4.47a
Rocky Mtn.	Freshwater	1	50-125	93.5a	0.25a	6.25a	8.0a	21.8a	6.25a	299a	59.0a	1420a	169a	0.25a	4.25a
Rocky Mtn.	Freshwater	1	125-200	80.0a	0.25a	3.50a	6.25a	21.0a	4.75a	304a	57.0a	14600a	197a	0.25a	3.75a
Rocky Mtn.	Water-N.A.	3	0-50	70.7a	0.25a	2.5a	3.83a	59.5a	2.58a	301a	83.2a	311a	190a	0.75a	0.92a
Rocky Mtn.	Water-N.A.	3	50-100	99.4a	0.25a	2.92a	6.83a	48.6a	3.50a	309a	98.9a	527a	159a	0.75a	1.67a
Waterton	Freshwater	5	0-100	167a	0.25a	9.25a	28.6a	32.7a	13.8a	207a	61.6a	15900a	1150a	0.60a	4.20a
Waterton	Freshwater	5	100-225	167a	0.25a	11.2a	23.6a	33.0a	14.7a	220a	56.7a	10800a	1530a	0.35a	2.50a
Waterton	Freshwater	5	225-350	171a	0.25a	8.75a	22.6a	45.6a	18.4a	232a	66.8a	6520a	878a	0.30a	1.80a
G. Prairie1	Freshwater	5	0-75	179a	0.07a	7.32a	9.16a	13.7a	10.6a	251a	61.7a	14500a	299a	0.75a	9.91a
G. Prairie1	Freshwater	5	75-150	176a	0.07a	5.69a	11.7a	11.9a	11.1a	265a	68.7a	9990a	289a	0.36a	7.08a
G. Prairie1	Freshwater	5	150-225	216a	0.07a	6.69a	12.7a	11.1a	9.04a	219a	83.6a	6780a	300a	0.68a	11.3a
G. Prairie2	Freshwater	4	0-30	222a	0.08a	5.53a	47.6a	39.5a	6.22a	235a	82.4a	2200a	225a	1.48a	59.1a
G. Prairie2	Freshwater	4	30-75	175a	0.07a	4.84a	13.4a	25.6a	5.98a	293a	101a	1710a	211a	0.61a	75.6a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Waste	Mo	Ni	Se
		(ug/g)		
Cold Lake	Freshwater	1.58a	2.35a	1.04a
Cold Lake	Freshwater	1.54a	1.76a	0.96a
Cold Lake	Freshwater	1.68a	2.40a	0.90a
Rocky Mtn.	Freshwater	0.31a	1.66a	0.75a
Rocky Mtn.	Freshwater	0.25a	1.75a	0.75a
Rocky Mtn.	Freshwater	0.25a	1.25a	0.75a
Rocky Mtn.	Water-N.A.	0.25a	0.67a	0.75a
Rocky Mtn.	Water-N.A.	0.25a	1.08a	0.75a
Waterton	Freshwater	3.10a	1.00a	3.40a
Waterton	Freshwater	2.55a	1.05a	1.75a
Waterton	Freshwater	2.30a	1.20a	1.30a
G. Prairie1	Freshwater	1.52a	1.24a	1.84a
G. Prairie1	Freshwater	1.03a	1.66a	1.40a
G. Prairie1	Freshwater	0.77a	1.72a	1.07a
G Prairie2	Freshwater	0.38a	1.94a	0.75a
G Prairie2	Freshwater	0.32a	2.83a	0.75a

Comparison of the mean values by depth of the DTPA extract data for the invert solid phase samples.

Location	N	Depth (cm)	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni	Se
										(ug/g)							
Rocky Mtn.	6	0-50	55.1a*	0.25a	1.75a	3.38a	39.9a	1.92a	318a	97.3a	1630a	387a	0.75a	1.63a	0.25a	0.42a	0.75a
Rocky Mtn.	2	50-100	42.4a	0.25a	0.75a	2.25a	30.1a	1.13a	335a	89.8a	1510a	404a	0.50a	1.13a	0.25a	0.25a	0.75a
Rocky Mtn.	1	100-150	75.5a	0.25a	2.25a	3.75a	30.0a	2.50a	299a	98.0a	1710a	407a	0.75a	2.00a	0.25a	0.50a	0.75a
G. Prairie	6	0-50	98.3a	0.03a	2.37a	3.73a	9.82a	1.81a	273a	22.9a	2460a	520a	1.35a	0.76a	0.29a	0.76a	0.75a
G. Prairie	6	50-125	91.0a	0.03a	1.96a	3.04a	8.14a	1.62a	274a	21.6a	2420a	527a	1.36a	0.80a	0.27a	0.70a	0.75a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by depth of the DTPA extract data for the KCl solid phase samples.

Location	N	Depth (cm)	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni
										(ug/g)						
Cold Lake	5	0-75	207a*	0.24a	7.08a	9.94a	52.1a	13.7a	171a	95.8a	2190a	7190a	3.80a	2.52a	1.54a	2.44a
Cold Lake	5	75-150	182a	0.24a	7.04a	8.98a	42.4a	14.8a	195a	85.9a	1710a	5870a	3.00a	2.68a	1.52a	2.96a
Cold Lake	4	150-225	198a	0.30a	7.50a	9.60a	56.3a	14.9a	171a	92.0a	1820a	6430a	3.38a	2.95a	1.80a	2.90a
Waterton	5	0-75	113a	0.25a	5.55a	30.8a	106a	11.9a	190a	192a	8970a	31600a	1.30a	2.80a	1.05a	1.05a
Waterton	5	75-175	106a	0.25a	6.43a	35.7a	158a	9.25a	171a	148a	7410ab	28700ab	0.85a	2.83a	0.85a	1.55a
Waterton	5	175-275	107a	0.25a	5.50a	35.8a	166a	7.88a	164a	202a	4994b	19900b	0.55a	2.65a	0.85a	1.85a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Depth (cm)	Se (ug/g)
Cold Lake	0-75	0.80a
Cold Lake	75-150	0.80a
Cold Lake	150-225	0.80a
Waterton	0-75	0.85a
Waterton	75-175	1.10a
Waterton	175-275	1.15a

Comparison of the mean values by depth of the DTPA extract data for the NaCl solid phase samples.

Location	N	Depth (cm)	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni
			(ug/g)													
Cold Lake	5	0–75	163a*	0.10a	6.96a	13.8a	28.8a	15.5a	96.2a	290a	24900a	122a	7.76a	5.88a	0.20a	0.72a
Cold Lake	5	75–150	181a	0.10a	4.58b	8.80b	19.2ab	14.6a	136a	205ab	19300a	74.8b	1.18a	5.68a	0.18a	0.80a
Cold Lake	5	150–225	169a	0.10a	3.98b	7.78b	15.0b	18.0a	168a	161b	16700a	72.3b	1.24a	5.08a	0.20a	0.86a
Slave Lake	4	0–20	282a	0.16a	13.9a	18.8a	16.7a	48.7a	175a	589a	2980a	251a	3.41a	6.16a	0.55a	3.08a
Slave Lake	1	0–50	284a	0.20a	18.4a	17.7a	15.8a	84.7a	287a	1750a	17900a	264a	10.6a	3.52a	0.29a	2.45a
Slave Lake	2	20–30	342a	0.14a	23.5a	23.0a	21.4a	51.8a	173a	1260a	4890a	169a	8.15a	3.39a	0.59a	3.28a
Slave Lake	1	20–50	293a	0.12a	17.8a	30.0a	15.7a	35.1a	255a	1030a	16000a	289a	7.03a	4.08a	0.28a	1.54a
Slave Lake	2	50–100	300a	0.13a	16.0a	16.1a	21.9a	31.6a	180a	1840a	15600a	259a	12.7a	4.27a	0.26a	2.44a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Depth (cm)	Se (ug/g)
Cold Lake	0–75	0.80a
Cold Lake	75–150	0.80a
Cold Lake	150–225	0.80a
Slave Lake	0–20	2.59a
Slave Lake	0–50	6.49a
Slave Lake	20–30	1.50a
Slave Lake	20–50	1.27a
Slave Lake	50–100	0.99a

10.8 COMPARISON OF THE MEAN VALUES BY HORIZONTAL POSITION OF THE DTPA EXTRACT DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by horizontal position of the DTPA extract data for the DAP solid phase samples.

Location	N	Hole No.	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni
									(ug/g)							
Cold Lake	3	1	55.6b*	0.25a	8.96a	28.0a	44.6a	12.0a	236bcd	65.8a	1090a	1080a	1.83a	47.9a	0.42b	0.92b
Cold Lake	2	2	74.4b	0.25a	7.63ab	29.4a	41.3a	20.0a	215cd	56.8a	1660a	2200a	2.13a	44.6a	0.63ab	1.25b
Cold Lake	3	3	77.2b	0.25a	4.67abc	19.9a	10.8a	5.42a	352abc	107a	3380a	333a	2.17a	78.5a	1.25a	3.75a
Cold Lake	3	4	221a	0.25a	5.58abc	17.8a	35.3a	20.3a	131d	156a	1680a	1650a	2.33a	70.5a	0.50b	1.42b
Cold Lake	3	5	261a	0.25a	5.67abc	18.3a	41.3a	20.9a	124d	179a	1910a	1780a	2.58a	64.7a	0.67ab	1.42b
Cold Lake	3	6	42.9b	0.25a	2.08bc	4.67a	5.75a	4.58a	475a	57.4a	2200a	420a	1.75a	171a	0.33b	1.58ab
Cold Lake	3	7	31.9b	0.25a	1.75c	4.08a	5.58a	3.42a	439ab	61.0a	1960a	290a	1.50a	164a	0.50b	1.50b

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Se (ug/g)
Cold Lake	3	1	0.83a
Cold Lake	2	2	0.75a
Cold Lake	3	3	0.75a
Cold Lake	3	4	1.00a
Cold Lake	3	5	1.00a
Cold Lake	3	6	0.75a
Cold Lake	3	7	0.75a

Comparison of the mean values by horizontal position of the DTPA extract data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P
				(ug/g)											
Cold Lake	Freshwater	3	1	252a*	0.13a	10.7a	20.2a	28.9a	32.8a	95.8b	176a	1580a	280a	3.73a	5.53a
Cold Lake	Freshwater	3	2	185a	0.17a	10.2a	23.2a	5.2a	22.5ab	170ab	115ab	1450b	312a	3.57a	4.73a
Cold Lake	Freshwater	3	3	253a	0.17a	9.93a	16.2a	19.1ab	19.3ab	137ab	128ab	1690ab	207a	3.73a	4.13a
Cold Lake	Freshwater	3	4	108a	0.10a	9.87a	7.17a	11.4b	13.2b	280a	41.8b	2960a	200a	3.57a	2.40a
Cold Lake	Freshwater	3	5	97.7a	0.10a	7.57a	5.90a	9.0b	12.5b	282a	52.3b	2840ab	2203a	2.93a	2.47a
Rocky Mtn.	Freshwater	3	18	88.7a	0.25a	5.50a	6.42a	22.8a	5.41a	297a	57.3ab	1400a	188a	0.25a	3.25a
Rocky Mtn.	Freshwater	1	19	79.5a	0.25a	4.75a	12.0a	18.8a	5.25a	307a	47.0b	1130a	91.0a	0.25a	4.25a
Rocky Mtn.	Freshwater	1	20	104a	0.25a	6.50a	12.6a	32.5a	6.00a	286a	67.5a	1700a	191a	0.25a	5.13a
Rocky Mtn.	Freshwater	1	21	84.5a	0.25a	5.25a	14.0a	24.8a	6.75a	312a	62.0ab	1760a	182a	0.25a	6.75a
Rocky Mtn.	Water-N.A.	2	6	66.3a	0.25a	2.38a	3.50a	44.6a	2.75a	324a	67.5a	345a	192a	0.75a	0.88a
Rocky Mtn.	Water-N.A.	2	7	105a	0.25a	3.13a	7.13a	56.8a	3.63a	286a	95.8a	671a	192a	0.75a	1.88a
Rocky Mtn.	Water-N.A.	2	8	84.3a	0.25a	2.63a	5.38a	60.8a	2.75a	305a	110a	241a	140a	0.75a	1.13a
Waterton	Freshwater	3	1	174a	0.25a	9.92a	26.2a	65.3a	20.3a	196a	56.0a	9240a	2120a	0.25a	1.58a
Waterton	Freshwater	3	2	191a	0.25a	13.8a	24.6a	36.4ab	18.0a	192a	102a	10300a	1160a	0.33a	2.08a
Waterton	Freshwater	3	3	190a	0.25a	10.8a	26.3a	22.9b	15.3a	204a	39.5a	15300a	650a	0.50a	3.75a
Waterton	Freshwater	3	4	157a	0.25a	7.25a	24.8a	26.3ab	12.8a	244a	64.8a	9200a	770a	0.50a	3.25a
Waterton	Freshwater	3	5	130a	0.25a	6.92a	22.8a	34.4ab	11.4a	262a	46.5a	11200a	1220a	0.50a	3.50a
G. Prairie1	Freshwater	3	6	168a	0.07a	6.97a	8.69a	16.5a	4.44a	275a	45.5a	7110a	345a	0.57a	3.27a
G. Prairie1	Freshwater	3	7	209a	0.07a	6.55a	16.1a	12.1a	15.4a	231a	123a	3090a	278a	0.55a	12.7a
G. Prairie1	Freshwater	3	8	180a	0.08a	5.84a	14.6a	12.6a	8.35a	236a	69.3a	4050a	304a	0.76a	25.1a
G. Prairie1	Freshwater	3	9	161a	0.06a	6.19a	11.9a	13.7a	12.5a	267a	41.6a	15900a	271a	0.74a	4.16a
G. Prairie1	Freshwater	3	10	226a	0.07a	7.30a	4.71a	9.55a	10.6a	216a	76.9a	22000a	282a	0.35a	1.98a
G. Prairie2	Freshwater	2	6	228a	0.09a	5.60a	24.1a	36.2a	7.47a	294a	110a	1470a	212a	0.91a	92.3a
G. Prairie2	Freshwater	2	7	277a	0.10a	7.67a	20.8a	26.8a	6.87a	257a	86.6a	1820a	216a	1.01a	148a
G. Prairie2	Freshwater	2	8	124a	0.05a	3.48a	47.8a	39.1a	4.49a	258a	57.2a	2600a	226a	1.26a	8.68a
G. Prairie2	Freshwater	2	9	166a	0.06a	3.99a	29.5a	28.1a	5.58a	247a	113a	1930a	217a	1.01a	20.6a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Concluded. Comparison of the mean values by horizontal position of the DTPA extract data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Mo	Ni (ug/g)	Se
Cold Lake	Freshwater	3	1	1.83a*	2.75a	1.37a
Cold Lake	Freshwater	3	2	1.57a	1.63a	0.93b
Cold Lake	Freshwater	3	3	1.67a	1.67a	0.93b
Cold Lake	Freshwater	3	4	1.63a	2.37a	0.80b
Cold Lake	Freshwater	3	5	1.30a	2.43a	0.80b
Rocky Mtn.	Freshwater	3	18	0.25b	1.58a	0.75a
Rocky Mtn.	Freshwater	1	19	0.25b	1.50a	0.75a
Rocky Mtn.	Freshwater	1	20	0.25b	1.88a	0.75a
Rocky Mtn.	Freshwater	1	21	0.50a	1.50a	0.75a
Rocky Mtn.	Water–N.A.	2	6	0.25a	0.75a	0.75a
Rocky Mtn.	Water–N.A.	2	7	0.25a	1.13a	0.75a
Rocky Mtn.	Water–N.A.	2	8	0.25a	0.75a	0.75a
Waterton	Freshwater	3	1	2.67a	1.33a	1.67a
Waterton	Freshwater	3	2	2.83a	1.33a	1.17a
Waterton	Freshwater	3	3	3.50a	1.08a	2.17a
Waterton	Freshwater	3	4	1.92a	1.00a	3.00a
Waterton	Freshwater	3	5	2.33a	0.67a	2.75a
G. Prairie1	Freshwater	3	6	0.93a	1.39a	0.93a
G. Prairie1	Freshwater	3	7	0.65a	1.73a	0.94a
G. Prairie1	Freshwater	3	8	0.53a	1.36a	0.79a
G. Prairie1	Freshwater	3	9	1.72a	1.51a	1.84a
G. Prairie1	Freshwater	3	10	1.70a	1.72a	2.65a
G. Prairie2	Freshwater	2	6	0.45a	2.78a	0.75a
G. Prairie2	Freshwater	2	7	0.49a	2.33a	0.75a
G. Prairie2	Freshwater	2	8	0.23a	1.39a	0.75a
G. Prairie2	Freshwater	2	9	0.22a	3.04a	0.75a

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* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by horizontal position of the DTPA extract data for the invert solid phase samples.

Location	N	Hole No.	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni	Se
										(ug/g)							
Rocky Mtn.	2	12	54.6a*	0.25a	1.25a	3.13a	34.1a	2.13a	319a	97.0a	1550a	392a	0.75a	2.25a	0.25a	0.50a	0.75a
Rocky Mtn.	1	13	69.0a	0.25a	2.00a	4.00a	34.0a	2.25a	304a	91.0a	1740a	400a	0.75a	2.50a	0.25a	0.50a	0.75a
Rocky Mtn.	1	14	47.8a	0.25a	1.50a	3.00a	30.5a	2.50a	336a	98.5a	1460a	340a	0.75a	1.25a	0.25a	0.50a	0.75a
Rocky Mtn.	3	15	56.8a	0.25a	1.67a	2.92a	30.7a	1.67a	322a	96.3a	1670a	432a	0.58a	1.25a	0.25a	0.33a	0.75a
Rocky Mtn.	1	16	51.5a	0.25a	1.75a	4.00a	95.5a	1.25a	291a	81.0a	1140a	312a	0.75a	1.50a	0.25a	0.25a	0.75a
Rocky Mtn.	1	17	42.8a	0.25a	1.50a	2.50a	9.25a	1.00a	340a	108a	2070a	407a	0.75a	0.50a	0.25a	0.25a	0.75a
G. Prairie	1	6	73.3a	0.03a	2.09a	3.31a	7.80a	1.70a	301a	29.2a	2320a	429a	1.42a	0.55a	0.16a	0.43a	0.75a
G. Prairie	2	7	82.0a	0.03a	2.19a	3.49a	8.42a	2.09a	301a	25.7a	2220a	482a	1.25a	0.67a	0.23a	0.56a	0.75a
G. Prairie	2	8	129a	0.03a	2.66a	4.22a	13.5a	2.00a	250a	20.5a	2570a	508a	1.44a	0.94a	0.45a	0.94a	0.75a
G. Prairie	2	9	73.7a	0.03a	1.38a	2.01a	6.22a	1.18a	278a	19.9a	2510a	542a	1.28a	0.73a	0.23a	0.63a	0.75a
G. Prairie	2	10	112a	0.03a	2.84a	4.59a	10.5a	1.93a	265a	23.8a	2530a	585a	1.42a	0.93a	0.31a	0.96a	0.75a
G. Prairie	2	11	89.1a	0.03a	1.91a	2.87a	7.23a	1.42a	258a	17.9a	2440a	547a	1.34a	0.74a	0.25a	0.71a	0.75a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by horizontal position of the DTPA extract data for the KCl solid phase samples.

Location	N	Hole No.	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni
									(ug/g)							
Cold Lake	3	1	120c*	0.27a	6.50b	6.27a	46.2a	10.3ab	255a	56.3c	1580a	5260ab	2.53a	1.93ab	1.53a	3.40a
Cold Lake	2	2	263a	0.25a	6.95ab	10.9a	36.5a	14.0a	149bc	113a	1590a	4790b	4.45a	3.20ab	1.90a	2.25a
Cold Lake	3	3	222ab	0.23a	7.63ab	12.1a	48.8a	18.6ab	145c	109ab	2020a	6800ab	3.10a	3.50a	1.80a	2.60a
Cold Lake	3	4	257a	0.27a	8.10a	12.5a	49.2a	20.7a	114c	126a	1930a	6530ab	2.87a	3.23ab	1.57a	2.77a
Cold Lake	3	5	138bc	0.27a	6.67ab	6.20a	64.0a	8.57b	226ab	58.5bc	2340a	8570a	4.37a	1.80b	1.33a	2.60a
Waterton	3	1	84.8a	0.25a	6.08a	36.7a	156a	8.13a	208a	61.4a	5150a	23000a	0.33a	1.83a	0.58a	1.08a
Waterton	3	2	110a	0.25a	5.92a	34.3a	132a	8.58a	175a	160a	7810a	29300a	0.50a	2.67a	0.83a	1.67a
Waterton	3	3	96.2a	0.25a	4.92a	28.2a	152a	7.58a	166a	289a	8360a	26900a	1.58a	3.33a	1.00a	1.17a
Waterton	3	4	115a	0.25a	5.58a	34.4a	148a	9.83a	177a	184a	6990a	24800a	1.58a	2.42a	1.00a	1.17a
Waterton	3	5	137a	0.25a	6.63a	36.8a	129a	14.3a	150a	210a	7330a	29600a	0.50a	3.54a	1.17a	2.33a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	N	Hole No.	Se (ug/g)
Cold Lake	3	1	0.80a
Cold Lake	2	2	0.80a
Cold Lake	3	3	0.80a
Cold Lake	3	4	0.80a
Cold Lake	3	5	0.80a
Waterton	3	1	1.17a
Waterton	3	2	0.92a
Waterton	3	3	1.08a
Waterton	3	4	1.00a
Waterton	3	5	1.00a

Comparison of the mean values by horizontal position of the DTPA extract data for the NaCl solid phase samples.

Location	N	Hole No.	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo	Ni	Se
										(ug/g)							
Cold Lake	3	1	146a*	0.10a	5.63a	10.3a	15.5a	10.1b	198a	167a	10590a	83.3a	0.97a	5.60b	0.17a	0.77b	0.80a
Cold Lake	3	2	143a	0.10a	4.60a	8.03a	14.7a	10.6b	147a	172a	21200a	76.5a	1.20a	4.53b	0.20a	0.57b	0.80a
Cold Lake	3	3	156a	0.10a	5.53a	9.20a	23.1a	17.2b	102a	250a	28200a	104a	1.37a	4.60b	0.20a	0.63b	0.80a
Cold Lake	3	4	209a	0.10a	4.33a	11.3a	26.8a	28.8a	133a	213a	17300a	92.2a	1.60a	7.73a	0.20a	1.23a	0.80a
Cold Lake	3	5	201a	0.10a	5.77a	11.7a	25.0a	13.4b	86.3a	292a	24000a	92.5a	1.83a	5.27b	0.20a	0.77b	0.80a
Slave Lake	1	1	299a	0.18a	20.8a	19.5a	22.1a	58.3a	148a	1010a	7930a	208a	5.43a	4.83a	0.66a	3.46a	1.55a
Slave Lake	2	2	369a	0.15a	17.2a	25.4a	21.0a	31.1a	126a	651a	1600a	280a	5.94a	4.83a	0.63a	2.76a	1.05a
Slave Lake	3	3	273a	0.16a	17.7a	16.9a	19.6a	57.1a	200a	2070a	18300a	295a	13.0a	4.13a	0.26a	2.30a	3.71a
Slave Lake	3	4	322a	0.12a	16.8a	23.0a	16.1a	53.4a	251a	1200a	9950a	205a	7.71a	3.81a	0.31a	2.41a	3.21a
Slave Lake	1	5	141b	0.14a	8.99a	8.76a	11.4a	28.4a	245a	292a	1180a	233a	1.13a	8.99a	0.41a	3.48a	0.81a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

10.9 COMPARISON OF THE MEAN VALUES BY DEPTH OF THE TOTAL ELEMENTAL ANALYSIS DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by depth of the total elemental analysis data for the DAP solid phase samples.

Location	N	Depth	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
		(cm)								(ug/g)						
Cold Lake	7	0–30	356a*	7550a	14200a	9620a	4550a	32.2a	108a	2370a	32.2a	26900a	22200a	2140a	81.9a	68.7a
Cold Lake	7	30–60	333a	7900a	13200a	13200a	4540a	32.3a	94.2a	1200a	32.6a	26100a	20700a	1830a	70.3a	57.0a
Cold Lake	6	60–90	294a	7570a	11300a	9550a	4260a	59.5a	105a	1350a	32.2a	19000a	16900a	1530a	53.8a	46.6a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ba	Ni	Sr	Li	Zr
			(ug/g)		
Cold Lake	235a	42.5a	126a	34.5a	90.6a
Cold Lake	238a	30.6a	128a	32.8a	80.7a
Cold Lake	254a	29.0a	110a	30.4a	73.4a

Comparison of the mean values by depth of the total elemental analysis data for the freshwater gel solid phase samples.

Location	Waste	N	Depth (cm)	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti
									(ug/g)						
Cold Lake	Freshwater	5	0–75	423a*	10730a	13690a	65780a	10120a	27.4a	114a	685a	31.7a	55700a	28100a	2770a
Cold Lake	Freshwater	5	75–150	408a	11130a	14350a	40600a	8840a	27.3a	104a	722a	30.4a	55700a	26700a	2690a
Cold Lake	Freshwater	5	150–225	406a	11070a	14720a	35060a	8640a	29.6a	103a	763a	33.3a	57200a	26900a	2790a
Rocky Mtn.	Freshwater	4	0–50	326a	4480a	9800a	6800a	2820a	32.2a	159a	941a	32.2a	35400a	21400a	2370a
Rocky Mtn.	Freshwater	1	50–125	466a	3440a	11900a	6530a	2700a	32.2a	147a	1050a	32.2a	49800a	27100a	3730a
Rocky Mtn.	Freshwater	1	125–200	404a	3400a	13600a	5660a	3290a	32.2a	189a	1810a	32.2a	36700a	28400a	3130a
Rocky Mtn.	Water–N.A.	3	0–50	338a	854a	14800a	6160a	13900a	32.2a	146a	275a	32.2a	3700a	12000a	1390a
Rocky Mtn.	Water–N.A.	3	50–100	256a	1300a	10200a	10700a	13900a	32.2a	149a	295a	32.2a	3460a	9090a	1280a
Waterton	Freshwater	5	0–100	363a	15900a	13800a	5500a	1820a	47.3a	207a	438a	35.5a	54600a	27600a	2260a
Waterton	Freshwater	5	100–225	413a	12500a	16400a	4770a	2180a	43.9a	191a	504a	34.6a	59800a	31700a	2700a
Waterton	Freshwater	5	225–350	501a	10600a	14700a	4900a	2600a	48.2a	215a	523a	51.6a	53000a	30100a	2620a
G.Prairie1	Freshwater	5	0–75	354a	14700a	14300a	6480a	2130a	28.3a	123a	1180a	31.4a	38900a	26200a	2850a
G.Prairie1	Freshwater	5	75–150	413a	10100a	15400a	6030a	2450a	28.4a	125a	1150a	32.8a	43400a	28400a	3120a
G.Prairie1	Freshwater	5	150–225	329a	9280a	16600a	5930a	2370a	35.4a	135a	1100a	35.7a	49100a	30900a	3350a
G.Prairie2	Freshwater	4	0–30	279a	7230a	15700a	4260a	1990a	31.1a	200a	1570a	35.9a	54200a	31600a	4010a
G.Prairie2	Freshwater	4	30–75	233a	5560a	17200a	4870a	1750a	31.8a	169a	1520a	35.7a	57600a	34000a	3950a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	V	Cr	Ba	Ni	Sr	Li	Zr
				(ug/g)			
Cold Lake	112a	87.8a	771a	34.3a	209a	45.4a	121a
Cold Lake	106a	80.1a	934a	33.4a	212a	41.4a	117a
Cold Lake	118a	77.9a	837a	37.5a	211a	47.9a	123a
Rocky Mtn.	78.8a	56.4a	331a	27.0b	136a	29.6a	74.8a
Rocky Mtn.	73.6a	73.6a	344a	25.7b	196a	29.1a	123a
Rocky Mtn.	108a	80.9a	162a	53.9a	135a	29.1a	108a
Rocky Mtn.	41.9a	40.5a	4.96a	33.6a	15.5a	29.1a	29.1a
Rocky Mtn.	44.4a	32.6a	24.1a	34.8a	69.4a	31.6a	29.1a
Waterton	86.1a	284a	371a	34.1a	166a	34.3a	117a
Waterton	106a	183a	333a	46.9a	161a	39.5a	120a
Waterton	90.1a	206a	436a	85.7a	171a	34.2a	108a
G.Prairie1	122a	159a	656a	31.1a	149a	47.7a	91.5a
G.Prairie1	132a	120a	527a	36.7a	121a	48.7a	101a
G.Prairie1	153a	123a	624a	42.3a	116a	59.3a	107a
G.Prairie2	151a	91.2a	625a	44.2a	112a	58.1a	118a
G.Prairie2	170a	96.2a	648a	42.7a	101a	61.1a	101a

Comparison of the mean values by depth of the total elemental analysis data for the invert solid phase samples.

Location	N	Depth (cm)	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
									(ug/g)							
Rocky Mtn.	6	0–50	165a*	4390a	17700a	6290a	3180a	32.2a	218a	867a	35.0a	53800a	33600a	3680a	181a	99.9a
Rocky Mtn.	2	50–100	153a	4460a	17100a	6700a	3080a	41.4a	217a	879a	32.2a	49600a	35600a	3860a	178a	102a
Rocky Mtn.	1	100–150	230a	6140a	17200a	6160a	3400a	32.2a	202a	864a	32.2a	55500a	35500a	3830a	173a	86.4a
G. Prairie	6	0–50	210a	4580a	17300a	7900a	3520a	24.8a	150a	857a	26.1a	51700a	32900a	3590a	182a	100a
G. Prairie	5	50–125	162a	4180a	16800a	8580a	3370a	25.1a	139a	840a	26.1a	50700a	30400a	3480a	177a	94.2a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ba	Ni	Sr	Li	Zr
			(ug/g)		
Rocky Mtn.	165a	45.1a	157a	62.9a	90.2a
Rocky Mtn.	127a	50.9a	140a	63.8a	102a
Rocky Mtn.	115a	28.8a	144a	57.6a	86.4a
G. Prairie	510a	39.1a	152a	60.3a	88.8a
G. Prairie	408a	36.2a	149a	58.2a	84.2a

Comparison of the mean values by depth of the total elemental analysis data for the KCl solid phase samples.

Location	N	Depth (cm)	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
									(ug/g)							
Cold Lake	5	0–75	392a*	10600a	32500a	33300a	8820a	28.1a	206a	782a	30.6a	59900a	28300a	3150a	135a	100a
Cold Lake	5	75–150	395a	9910a	28000a	34700a	8450a	26.6a	158a	750a	31.8a	56800a	26900a	2990a	126a	79.9a
Cold Lake	4	150–225	390a	9630a	29000a	35000a	8530a	25.9a	185a	799a	30.5a	57100a	27300a	3040a	136a	74.4a
Waterton	5	0–75	329a	12000a	48600a	5630a	3120a	45.3a	413a	322a	32.2a	22900a	20500a	1670a	61.7a	74.8a
Waterton	5	75–175	330a	10400ab	40000ab	3370a	3220a	54.1a	542a	337a	32.4a	21500a	20500a	1760a	62.6a	106a
Waterton	5	175–275	283a	7720b	30200b	5720a	2990a	65.7a	551a	303a	32.2a	11800a	16700a	1550a	48.5a	82.9a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ba	Ni	Sr	Li	Zr
			(ug/g)		
Cold Lake	673a	34.4a	224a	61.2a	130a
Cold Lake	661a	33.4a	193a	55.4a	123a
Cold Lake	662a	35.5a	217a	58.6a	132a
Waterton	737a	29.4a	198a	50.8a	69.3a
Waterton	844a	31.1a	205a	47.5a	80.9a
Waterton	1370a	32.7a	644a	46.6a	63.6a

Comparison of the mean values by depth of the total elemental analysis data for the NaCl solid phase samples.

Location	N	Depth (cm)	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V
									(ug/g)						
Cold Lake	5	0–75	266a*	60800a	10800a	79000a	16000a	14.2a	97.3a	397a	24.2a	33900a	17100a	1780a	45.9a
Cold Lake	5	75–150	281a	39200a	10400a	48500b	12900a	12.1a	68.9a	358a	24.0a	33900a	15300a	1710a	43.0a
Cold Lake	5	150–225	301a	37600a	12000a	43000b	12100a	11.5a	67.3a	437a	24.2a	38900a	17600a	2110a	54.2a
Slave Lake	4	0–20	481a	5650a	13500a	7880bc	3230a	57.1a	99.6a	711a	18.3a	29400a	32900a	2630a	112a
Slave Lake	1	0–50	655a	21400a	10500a	14900abc	8480a	69.1a	68.0a	310a	15.0a	2000a	26400a	1520a	41.1a
Slave Lake	2	20–30	680a	7370a	9540a	20500a	10700a	123a	87.0a	426a	16.5a	2640a	41500a	1440a	54.5a
Slave Lake	1	20–50	636a	18000a	8410a	17700ab	7020a	64.8a	65.4a	330a	15.0a	3740a	25500a	1310a	39.0a
Slave Lake	2	50–100	337a	22000a	7510a	2590c	5590a	52.4a	70.6a	299a	15.0a	2500a	18000a	1210a	37.1a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cr	Ba	Ni	Sr	Li	Zr
			(ug/g)			
Cold Lake	72.1a	403a	17.7a	205a	46.8a	81.0a
Cold Lake	53.4a	398a	20.2a	171a	47.7a	78.5a
Cold Lake	56.3a	447a	21.2a	171a	50.2a	97.5a
Slave Lake	211a	210a	43.5a	75.1a	49.2a	85.7a
Slave Lake	696a	110a	34.4a	93.7a	56.2a	8.39a
Slave Lake	106a	562a	62.6a	171a	41.9a	16.8a
Slave Lake	126a	68.8a	34.1a	200a	57.1a	53.7a
Slave Lake	53.3a	38.9a	28.9a	19.2a	43.0a	11.9a

10.10 COMPARISON OF THE MEAN VALUES BY HORIZONTAL POSITION OF THE TOTAL ELEMENTAL ANALYSIS DATA FOR THE SOLID PHASE SAMPLES

Comparison of the mean values by horizontal position of the total elemental analysis of the DAP solid phase samples.

Location	N	Hole No.	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V
										(ug/g)					
Cold Lake	3	1	192b*	4950b	7290a	11900a	5620a	32.2a	127a	1200a	32.2a	2580c	12900a	972b	41.9a
Cold Lake	2	2	231b	5870b	9800a	12300a	6180a	128a	124a	1930a	32.2a	2980c	15600a	1380ab	51.0a
Cold Lake	3	3	459a	8840ab	15700a	6810a	2440b	32.5a	103a	1340a	32.9a	51100a	29100a	2920a	122.9a
Cold Lake	3	4	349ab	7600ab	13200a	15600a	5980a	32.2a	122a	2300a	32.2a	11900bc	20900a	1570ab	57.0a
Cold Lake	3	5	312ab	8020ab	13600a	14200a	5760a	32.2a	123a	2140a	32.2a	10400c	19800a	1600ab	56.6a
Cold Lake	3	6	365ab	8980a	15000a	6180a	2950b	32.2a	71.7a	1590a	32.2a	42100a	20300a	2190ab	71.7a
Cold Lake	3	7	352ab	8760ab	14600a	6430a	2770b	32.2a	54.5a	1220a	32.2a	39100ab	19100a	2000ab	73.0a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cr	Ba	Ni	Sr	Li	Zr
			(ug/g)			
Cold Lake	35.0a	85.8a	25.8a	60.3a	29.1a	38.3a
Cold Lake	42.2a	74.0a	30.1a	75.6a	29.1a	29.5a
Cold Lake	68.5a	332a	44.0a	144a	42.7a	120a
Cold Lake	67.7a	181a	28.6a	124a	30.1a	67.4a
Cold Lake	66.3a	292a	37.9a	142a	29.1a	65.9a
Cold Lake	62.4a	320a	35.6a	142a	37.8a	116a
Cold Lake	54.6a	358a	36.3a	144a	29.1a	117a

Comparison of the mean values by horizontal position of the total elemental analysis data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe
				(ug/g)										
Cold Lake	Freshwater	3	1	393a*	10000a	13500a	61700a	9100a	22.8a	111ab	638a	30.1ab	52500a	25900a
Cold Lake	Freshwater	3	2	342a	9720a	12500a	90200a	10400a	22.5a	126a	622a	27.1b	49300a	24900a
Cold Lake	Freshwater	3	3	407a	10900a	14100a	46900a	8650a	28.1a	108ab	741a	28.2b	53700a	25700a
Cold Lake	Freshwater	3	4	454a	12500a	15800a	19500a	9140a	36.1a	97.7ab	811a	39.1a	62900a	30100a
Cold Lake	Freshwater	3	5	467a	11800a	15400a	17500a	8750a	30.9a	92.3b	806a	34.7ab	62700a	29600a
Rocky Mtn.	Freshwater	3	18	389a	3140a	12100a	6210a	2830a	32.19a	153a	1240a	32.2a	39600a	26100a
Rocky Mtn.	Freshwater	1	19	272a	2620a	5790a	5490a	2320a	32.19a	124a	742a	32.2a	24500a	17200a
Rocky Mtn.	Freshwater	1	20	343a	4530a	12000a	8170a	4490a	32.19a	218a	1280a	32.2a	39600a	22200a
Rocky Mtn.	Freshwater	1	21	394a	8180a	10800a	7090a	1970a	32.19a	172a	887a	32.2a	42000a	23400a
Rocky Mtn.	Water-N.A.	2	6	351a	900a	14800a	8360a	12000a	32.2a	132a	281a	32.2a	3590a	11400a
Rocky Mtn.	Water-N.A.	2	7	312a	1510a	11900a	9700a	13200a	32.2a	165a	326a	32.2a	4560a	11600a
Rocky Mtn.	Water-N.A.	2	8	229a	820a	10700a	7300a	16500a	32.2a	144a	248a	32.2a	2590a	8570a
Waterton	Freshwater	3	1	423a	10800a	18600a	3330a	1420a	48.8a	285a	537a	43.1a	68700a	35500a
Waterton	Freshwater	3	2	428a	11800a	16700a	5100a	1730a	43.6a	219ab	531a	38.0a	72100a	32400a
Waterton	Freshwater	3	3	363a	15500a	12100a	6200a	2800a	38.9a	142b	427a	34.2a	50900a	27000a
Waterton	Freshwater	3	4	478a	12400a	13300a	4160a	2320a	49.1a	178ab	473a	51.6a	43400a	26900a
Waterton	Freshwater	3	5	436a	14400a	14200a	6550a	2770a	51.8a	199ab	474a	36.0a	44500a	27700a
G. Prairie1	Freshwater	3	6	240b	7920a	17400a	5190a	2740a	33.1a	149a	1320ab	36.0a	49200a	29100a
G. Prairie1	Freshwater	3	7	301b	8190a	14500a	5330a	2550a	28.7a	120ab	887b	33.5a	49400a	28000a
G. Prairie1	Freshwater	3	8	308b	8670a	16000a	5500a	2470a	32.9a	126ab	1010b	37.5a	57800a	31000a
G. Prairie1	Freshwater	3	9	687a	15800a	15600a	7800a	2250a	27.8a	140ab	1500a	31.0a	33800a	29800a
G. Prairie1	Freshwater	3	10	290b	16200a	13700a	6900a	1600a	31.0a	102b	985b	28.7a	28800a	24600a
G. Prairie2	Freshwater	2	6	162a	4900a	15400a	5400a	2100a	35.6a	191a	1820a	34.5a	50200a	34100a
G. Prairie2	Freshwater	2	7	314a	6770a	16200a	4860a	1960a	37.1a	163a	2320a	36.8a	55900a	34700a
G. Prairie2	Freshwater	2	8	310a	7490a	17400a	3250a	1840a	26.7a	208a	1000a	35.6a	60400a	31600a
G. Prairie2	Freshwater	2	9	237a	6410a	16700a	4760a	1560a	26.4a	176a	1050a	36.3a	57300a	30900a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Concluded. Comparison of the mean values by horizontal position of the total elemental analysis data for the freshwater gel solid phase samples.

Location	Waste	N	Hole No.	Ti	V	Cr	Ba	Ni	Sr	Li	Zr
								(mg/L)			
Cold Lake	Freshwater	3	1	2470a*	104a	75.3ab	733a	30.5ab	208a	36.4ab	104b
Cold Lake	Freshwater	3	2	2370a	96.0a	67.3a	716a	29.4ab	223a	32.8b	95.0b
Cold Lake	Freshwater	3	3	2650a	105a	82.2ab	796a	27.9b	217a	37.1ab	112b
Cold Lake	Freshwater	3	4	3220a	132a	100a	948a	45.4a	193a	61.0a	158a
Cold Lake	Freshwater	3	5	3050a	123a	84.8ab	1040a	42.0ab	212a	57.1ab	133ab
Rocky Mtn.	Freshwater	3	18	3240a	76.9a	67.9a	242a	35.1a	160a	29.1b	110a
Rocky Mtn.	Freshwater	1	19	1430a	74.2a	49.5a	544a	25.7a	98.9a	29.1b	49.5a
Rocky Mtn.	Freshwater	1	20	2570a	93.5a	77.6a	311a	31.2a	125a	31.2a	77.6a
Rocky Mtn.	Freshwater	1	21	2610a	98.5a	49.3a	246a	25.7a	172a	29.1b	73.9a
Rocky Mtn.	Water-N.A.	2	6	1490a	47.0a	36.8a	15.4a	37.0a	40.9a	31.5a	29.1a
Rocky Mtn.	Water-N A.	2	7	1470a	47.6a	41.6a	25.7a	39.1a	54.2a	30.4a	29.1a
Rocky Mtn.	Water-N.A.	2	8	1040a	34.8a	31.3a	2.46a	26.6a	32.4a	29.1a	29.1a
Waterton	Freshwater	3	1	3030a	106a	228a	212a	48.8a	172a	42.1a	146a
Waterton	Freshwater	3	2	2860a	110a	151a	356a	42.8a	194a	44.0a	127ab
Waterton	Freshwater	3	3	2140a	80.3a	188a	395a	36.4a	178a	30.3a	102b
Waterton	Freshwater	3	4	2350a	87.1a	303a	415a	108a	127a	30.1a	93.8b
Waterton	Freshwater	3	5	2250a	87.7a	251a	520a	42.2a	159a	33.7a	107ab
G. Prairie1	Freshwater	3	6	3480a	155a	132a	565a	40.3a	112a	62.0a	110a
G. Prairie1	Freshwater	3	7	3130a	137a	90.1a	680a	36.2a	119a	45.5a	99.6a
G. Prairie1	Freshwater	3	8	3400a	154a	95.3a	615a	39.1a	127a	57.6a	109a
G. Prairie1	Freshwater	3	9	2740a	115a	157a	639a	33.7a	129a	42.3a	86.2a
G. Prairie1	Freshwater	3	10	2780a	117a	196a	513a	34.4a	155a	52.1a	94.5a
G. Prairie2	Freshwater	2	6	4120a	161a	97.3a	630a	47.1a	94.4a	64.0a	119a
G. Prairie2	Freshwater	2	7	4330a	166a	93.9a	614a	50.5a	113a	61.2a	119a
G. Prairie2	Freshwater	2	8	3970a	160a	91.5a	637a	38.2a	112a	55.9a	113a
G. Prairie2	Freshwater	2	9	3490a	155a	92.1a	665a	37.9a	106a	56.4a	88.2a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Comparison of the mean values by horizontal position of the total elemental analysis of the invert solid phase samples.

Location	N	Hole No.	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
									(ug/g)							
Rocky Mtn.	2	12	147a*	4720a	17900ab	7110a	3220a	32.2a	199b	864a	32.2b	53500a	34300a	3960a	186a	106a
Rocky Mtn.	1	13	172a	4770a	18700a	7040a	2900a	32.2a	172b	837a	49.20a	54800a	34800a	4060a	197a	98.4a
Rocky Mtn.	1	14	216a	4370a	18100ab	7060a	3500a	32.2a	216b	835a	32.2b	50500a	37700a	3760a	190a	114a
Rocky Mtn.	3	15	201a	5000a	16900ab	6410a	3190a	38.4a	216ab	957a	32.2b	53000a	34600a	3690a	168a	91.7a
Rocky Mtn.	1	16	125a	3490a	13300b	3690a	3510a	32.2a	374a	722a	32.2b	38000a	26900a	2740a	125a	74.7a
Rocky Mtn.	1	17	115a	4420a	20800a	6080a	2720a	32.2a	138b	829a	32.2b	67900a	30500a	4100a	230a	115a
G. Prairie	1	6	314a	6940a	13700a	548a	2390a	28.5a	152a	891ab	28.5a	40300a	28300a	3240a	144a	83.6a
G. Prairie	2	7	249a	5540ab	16200a	8240a	3190a	19.6a	137a	857ab	24.7a	50400a	31200a	3500a	170a	94.1a
G. Prairie	2	8	191a	3990b	17900a	5580a	2650a	26.1a	148a	976a	33.9a	53400a	31900a	3570a	185a	102a
G. Prairie	2	9	111a	3730b	17900a	10100a	3900a	24.2a	147a	751b	22.2a	53900a	31800a	3630a	189a	96.9a
G. Prairie	2	10	191a	3980b	17800a	11000a	5150a	26.5a	154a	859ab	25.5a	55400a	33900a	3660a	189a	107a
G. Prairie	2	11	135a	3490b	17100a	7400a	2990a	26.7a	135a	78.b	23.0a	48700a	31900a	3490a	183a	94.6a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ba	Ni	Sr	Li	Zr
			(ug/g)		
Rocky Mtn.	133b	53.1a	159a	66.0a	106a
Rocky Mtn.	148b	49.2a	172a	73.8a	123a
Rocky Mtn.	139b	51.0a	141a	62.8a	102a
Rocky Mtn.	124b	41.0a	141a	50.6a	91.7a
Rocky Mtn.	249a	25.7a	125a	49.8a	49.8a
Rocky Mtn.	184ab	46.1a	184a	92.2a	69.1a
G. Prairie	192a	32.1a	161a	43.9a	79.3a
G. Prairie	588a	33.6a	167a	50.6a	78.2a
G. Prairie	600a	40.1a	134a	58.7a	90.6a
G. Prairie	346a	34.4a	150a	63.1a	84.4a
G. Prairie	608a	46.0a	166a	70.6a	96.8a
G. Prairie	313a	37.8a	131a	61.7a	87.3a

Comparison of the mean values by horizontal position of the total elemental analysis of the KCl solid phase samples.

Location	N	Hole No.	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V
			(ug/g)												
Cold Lake	3	1	406a*	9750a	28400a	26100a	8560a	28.7a	186a	847a	34.3a	59200a	27400a	3120a	142a
Cold Lake	2	2	413a	10000a	27000a	34700a	8480a	25.7a	165a	766a	28.9a	58800a	28300a	3050a	126a
Cold Lake	3	3	386a	10300a	30100a	45200a	8540a	24.1a	181a	759a	27.3a	55100a	26700a	2960a	122a
Cold Lake	3	4	378a	10300a	29300a	42200a	8780a	24.5a	170a	761a	32.0a	57700a	27600a	3040a	127a
Cold Lake	3	5	387a	10100a	33600a	23300a	8630a	31.3a	206a	742a	31.9a	59400a	27800a	3150a	142a
Waterton	3	1	410a	9080a	38000a	4350a	2720a	57.2a	503a	402a	32.5a	35600a	25800a	2260a	79.4a
Waterton	3	2	295ab	9800a	39600a	6390a	3390a	49.7a	449a	306abc	32.2a	14100ab	17100ab	1470bc	49.9ab
Waterton	3	3	232b	10700a	36500a	4020a	3080a	61.7a	469a	237c	32.2a	4660b	12600b	1090c	35.1b
Waterton	3	4	289ab	9800a	34800a	4580a	2760a	55.3a	548a	274bc	32.2a	12700ab	16000ab	1420bc	46.7ab
Waterton	3	5	344ab	11100a	48900a	5190a	3440a	51.5a	541a	386ab	32.2a	26600ab	24600ab	2070ab	77.0a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Cr	Ba	Ni	Sr	Li	Zr
	(ug/g)					
Cold Lake	84.5a	698a	34.2ab	212a	57.3ab	138ab
Cold Lake	68.8a	651a	32.0b	204a	49.2b	122ab
Cold Lake	90.0a	640a	30.8b	241a	55.2ab	126ab
Cold Lake	83.8a	651a	34.7ab	218a	56.8ab	110b
Cold Lake	95.2a	684a	38.9a	177a	70.3a	142a
Waterton	107a	862a	39.9a	193a	44.6b	114a
Waterton	83.7a	863a	25.8a	199a	48.5ab	60.5bc
Waterton	72.0a	1030a	25.8a	472a	41.4b	42.4c
Waterton	69.5a	1460a	26.6a	691a	41.6b	49.8bc
Waterton	107.8a	709a	37.2a	191a	65.2a	89.6ab

Comparison of the mean values by horizontal position of the total elemental analysis of the NaCl solid phase samples.

Location	N	Hole No.	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
										(ug/g)						
Cold Lake	3	1	300a*	26000a	12900a	43900a	11100a	19.4a	68.3a	422a	24.5a	41000a	18700a	2060a	60.6a	59.8a
Cold Lake	3	2	199a	38600a	8520a	51600a	11200a	9.0b	51.0a	309a	23.8a	30400a	13100a	1350a	37.9a	42.6a
Cold Lake	3	3	259a	69300a	10600a	67000a	15500a	11.0ab	82.7a	385a	23.8a	33100a	16300a	1740a	42.1a	63.0a
Cold Lake	3	4	345a	41300a	12000a	56000a	15000a	8.8b	97.3a	437a	23.8a	37400a	17300a	2240a	47.5a	59.8a
Cold Lake	3	5	310a	54200a	11400a	65700a	15800a	14.8ab	89.8a	434a	24.7a	35800a	17900a	1950a	50.5a	77.7a
Slave Lake	2	1	631a	10400a	11900a	13900a	8400a	96.7a	104a	619a	18.9b	16700a	38400a	2200a	95.1a	101a
Slave Lake	2	2	450a	4470a	12000a	16000a	5690a	74.5a	97.5a	624a	15.2bc	16400a	35100a	2120a	89.0a	102a
Slave Lake	2	3	483a	25100a	9020a	8520a	7230a	58.7a	62.7a	275a	15.0c	1580a	20300a	1310a	34.8a	368a
Slave Lake	3	4	587a	12200a	8540a	8860a	5470a	74.3a	70.0a	358a	15.0c	4060a	28200a	1380a	41.8a	252a
Slave Lake	1	5	359a	4370a	15700a	6770a	2030a	30.8a	108a	823a	22.9a	52000a	30200a	3240a	149a	85.4a

* Treatment means of each waste in any one column not followed by a common letter are significantly different at 0.01 probability by Tukey's Studentized Range (HSD) Test.

Location	Ba	Ni	Sr	Li	Zr
			(ug/g)		
Cold Lake	475a	24.3a	162a	48.2a	116a
Cold Lake	377a	16.0a	159a	34.5a	63.9b
Cold Lake	377a	16.4a	187a	54.5a	75.3ab
Cold Lake	426a	16.7a	193a	45.1a	85.8ab
Cold Lake	427a	25.0a	208a	58.9a	87.5ab
Slave Lake	557a	61.5a	125a	53.8a	54.7a
Slave Lake	337a	45.1a	132a	41.0a	57.2a
Slave Lake	89.4a	29.3a	58.8a	50.5a	8.39a
Slave Lake	34.6a	37.9a	80.6a	44.6a	31.5a
Slave Lake	152a	39.8a	99.3a	56.0a	127a

10.11 PROPERTIES OF THE DRILLING WASTE AND SOIL MATERIALS USED IN THE POT EXPERIMENTS

Data are provided for:

Chemical and Physical Properties.

Saturated Paste Extract Properties.

DTPA Extract Properties.

Total Elemental Analysis.

Chemical and physical properties of the drilling waste and soil materials used in the pot experiments.

Waste	Location	pH		ANC	CaCO3 Eq	Extractable Ions					TC	Oil	Sand	Silt	Clay	Tex.
		H2O	CaCl2			Na	K	Ca	Mg	CEC						
				(%)		(meq/100 g)							(%)			
DAP	Cold Lake	11.90	11.90	35.07	11.15	7.03	4.64	303.61	18.17	29.5	2.21	0.58	37	49	14	L
Freshwater	Cold Lake	11.40	11.60	12.08	5.70	14.34	1.34	84.11	5.75	22.9	3.23	0.92	46	38	16	L
Freshwater1	G. Prairie	10.00	9.60	6.65	6.31	22.90	0.80	48.60	2.52	18.9	2.12	0.09	36	38	26	SiL
Freshwater	Rocky Mtn.	8.80	8.20	4.94	5.67	6.62	0.46	18.47	1.51	8.3	4.19	0.42	69	21	10	SL
Freshwater	Waterton	10.10	9.70	9.25	6.23	66.55	2.59	29.70	1.69	40.6	5.81	1.94	12	22	66	HC
Invert	Rocky Mtn.	8.10	8.30	4.68	4.06	15.89	3.26	79.50	4.72	11.1	8.91	6.15	73	16	11	SL
Invert	G. Prairie	9.50	9.30	3.46	3.28	8.46	1.49	60.62	1.15	13.0	11.35	8.23	69	24	7	SL
KCl	Cold Lake	9.20	9.70	7.81	6.36	17.70	22.00	35.73	1.77	20.1	6.17	2.96	42	36	22	L
KCl	Waterton	8.30	8.50	10.11	8.03	60.38	393.32	74.68	7.95	16.2	6.24	3.23	32	38	30	CL
NaCl	Cold Lake	7.90	8.10	22.75	16.45	56.44	0.68	147.28	13.22	12.6	5.08	0.49	33	37	30	CL
NaCl	Slave Lake	10.30	10.20	16.96	12.77	71.50	0.81	88.12	8.16	17.4	2.40	0.12	51	33	16	L
Washed Inv.	G. Prairie	8.50	N/A	3.50	3.49	N/A	N/A	N/A	N/A	N/A	8.79	6.75	N/A	N/A	N/A	N/A
Water-N.A.	Rocky Mtn.	7.60	7.90	60.87	60.91	1.77	0.35	102.51	3.40	6.4	9.67	1.55	36	47	17	L
Soil (DAP)	Cold Lake	6.20	5.80	0.00	0.00	0.10	0.73	13.27	4.99	11.1	0.66	N/A	49	34	17	L
Soil	Cold Lake	5.80	5.90	0.00	0.00	0.60	0.42	5.31	1.74	9.5	0.49	N/A	64	19	17	SL
Soil	Slave Lake	5.20	4.80	0.00	0.00	0.04	0.37	5.57	0.97	11.9	1.97	N/A	35	50	15	SiL
Soil	G. Prairie	5.20	5.00	0.00	0.00	0.07	0.67	10.38	2.39	23.8	2.53	N/A	28	50	22	SiL
Soil	Rocky Mtn.	5.20	4.30	0.00	0.00	0.10	0.75	7.09	3.11	25.4	2.54	N/A	43	42	15	L
Soil	Waterton	6.30	6.00	0.00	0.00	0.01	1.59	49.53	8.33	38.3	5.43	N/A	45	35	20	L

ANC = Acid Neutralizing Capacity; CaCO3 Eq = Calcium carbonate equivalent (g CaCO3 eq/100 g); CEC = Cation Exchange Capactity; TC = Total Carbon; Tex. = Texture.

Saturated paste extract data for the drilling waste and soil materials used in the pot experiments.

Waste	Location	Sat'n	E.C.	pH	Alk.	Cl	Ca	Mg	Na	K	Sr	S
		(%)	(dS/m)						(mg/L)			
DAP	Cold Lake	87.00	12.33	11.72	2180.0	2010.0	470.50	<0.100	1133.04	674.10	4.027	523.70
Freshwater	Cold Lake	88.50	7.66	11.08	360.0	1020.0	174.50	0.032	1874.10	65.30	0.630	1365.00
Freshwater1	G. Prairie	118.00	10.12	9.35	157.0	233.0	375.80	2.140	2942.00	33.00	2.773	1450.70
Freshwater	Rocky Mtn.	54.50	3.49	8.20	225.0	48.0	12.47	3.560	915.44	30.32	0.373	573.40
Freshwater	Waterton	2.61	8.81	9.90	1690.0	915.0	2.78	0.150	2245.84	134.50	0.218	1093.90
Invert	Rocky Mtn.	49.00	36.70	7.95	154.0	18200.0	6860.00	115.900	2495.84	348.00	96.500	252.90
Invert	G. Prairie	42.50	40.50	9.17	298.0	20390.0	9560.00	8.260	3900.00	287.30	82.860	294.80
KCl	Cold Lake	70.50	56.30	8.86	89.3	20800.0	1335.00	11.496	5389.10	13789.80	9.494	1895.00
KCl	Waterton	63.00	103.80	8.32	142.0	52400.0	2120.00	128.480	8805.84	32620.00	38.620	1793.90
NaCl	Cold Lake	62.50	140.20	10.09	112.0	84000.0	2860.00	<0.100	50759.10	343.80	4.807	1355.00
NaCl	Slave Lake	57.50	66.20	7.90	1200.0	44300.0	4940.00	540.700	21580.00	212.00	74.680	627.90
Washed Inv.	G. Prairie	42.00	2.40	7.55	77.5	312.6	224.50	3.200	127.20	22.40	1.878	112.90
Water-N.A.	Rocky Mtn.	59.50	7.37	7.62	63.0	2310.0	1148.50	164.170	532.94	94.66	18.752	518.90
Soil (DAP)	Cold Lake	37.50	0.19	6.34	54.0	29.0	27.61	7.650	7.27	30.07	0.126	8.22
Soil	Cold Lake	35.00	0.21	6.40	69.4	22.8	21.20	5.995	13.80	16.40	0.116	6.80
Soil	Slave Lake	38.00	0.40	5.80	59.7	36.7	65.40	9.930	18.90	18.40	0.239	38.50
Soil	G. Prairie	45.50	0.24	6.10	43.8	26.2	33.00	6.210	19.60	17.50	0.192	14.20
Soil	Rocky Mtn.	48.00	0.13	5.82	33.0	11.0	17.08	2.930	3.16	24.41	0.044	4.41
Soil	Waterton	66.00	0.76	5.26	180.0	14.0	142.65	24.040	15.91	73.81	0.266	89.75

Sat'n = Saturation; E.C. = Electrical Conductivity (dS/m); Alk. = Alkalinity (mg $CaCO_3$/ L); SAR = Sodium Adsorption Ratio.

Continued. Saturated paste extract data for the drilling waste and soil materials used in the pot experiments.

Waste	Location	Al	Cr	Fe	V	Ti	Cd	Cu	Pb	Zn	Mn	Li	B
								(mg/L)					
DAP	Cold Lake	2.084	0.059	<0.010	<0.030	0.023	<0.010	<0.010	<0.100	0.143	<0.006	0.060	<0.040
Freshwater	Cold Lake	1.110	0.156	<0.010	0.069	<0.010	<0.010	0.046	<0.100	0.196	<0.006	0.014	0.197
Freshwater1	G. Prairie	1.930	<0.020	0.015	<0.030	0.030	<0.010	0.041	<0.100	0.300	0.009	<0.040	0.241
Freshwater	Rocky Mtn.	0.303	<0.020	0.060	<0.030	<0.010	<0.010	<0.010	<0.100	0.129	0.007	<0.040	0.091
Freshwater	Waterton	0.401	0.719	0.310	0.135	<0.010	<0.010	0.082	<0.100	0.368	0.010	<0.040	0.368
Invert	Rocky Mtn.	15.227	<0.020	0.021	<0.030	0.084	<0.010	0.459	0.128	0.394	0.047	0.356	0.342
Invert	G. Prairie	16.470	<0.020	0.010	0.065	0.153	<0.010	0.179	0.152	0.340	0.007	0.212	0.799
KCl	Cold Lake	4.216	<0.020	<0.001	<0.030	<0.010	<0.010	<0.010	<0.100	0.471	0.004	0.299	0.313
KCl	Waterton	5.359	<0.020	<0.010	<0.030	0.015	<0.010	<0.010	<0.100	1.108	0.139	1.411	0.075
NaCl	Cold Lake	6.581	<0.020	<0.010	<0.030	<0.010	<0.010	<0.010	<0.100	<0.002	<0.006	<0.040	0.077
NaCl	Slave Lake	11.830	0.040	0.034	<0.030	0.058	<0.010	0.077	<0.100	1.212	0.398	0.924	1.115
Washed Inv.	G. Prairie	0.980	<0.020	<0.010	<0.030	<0.010	<0.010	<0.010	<0.100	0.133	0.016	<0.040	0.293
Water-N.A.	Rocky Mtn.	3.718	<0.020	0.014	<0.030	0.039	<0.010	0.013	<0.100	0.208	0.064	0.833	0.447
Soil (DAP)	Cold Lake	8.989	<0.020	15.674	0.040	1.201	<0.010	0.078	0.107	0.374	0.101	<0.040	0.062
Soil	Cold Lake	5.195	<0.020	14.953	0.048	1.114	<0.010	0.153	<0.100	0.273	0.223	<0.040	0.069
Soil	Slave Lake	2.870	<0.020	2.374	<0.030	0.103	<0.010	0.063	<0.100	0.950	1.678	<0.040	0.376
Soil	G. Prairie	2.760	<0.020	8.474	<0.030	0.922	<0.010	0.043	<0.100	0.329	0.458	<0.040	0.228
Soil	Rocky Mtn.	5.768	<0.020	5.071	<0.030	0.443	<0.010	<0.010	0.513	0.435	0.167	<0.040	<0.040
Soil	Waterton	0.712	<0.020	0.105	<0.030	<0.010	<0.010	0.012	0.476	0.245	0.096	<0.040	<0.040

Concluded. Saturated paste extract data for the drilling waste and soil materials used in the pot experiments.

Waste	Location	Ba	P	Mo	Ni	Se	Co	Si	As	SAR
		(mg/L)								
DAP	Cold Lake	0.551	0.106	<0.050	<0.030	<0.300	<0.010	4.299	<0.030	14
Freshwater	Cold Lake	0.028	0.159	1.587	<0.030	0.062	<0.010	21.510	0.117	39
Freshwater1	G. Prairie	0.085	0.105	0.706	<0.030	<0.300	<0.010	12.190	0.065	42
Freshwater	Rocky Mtn.	0.010	0.300	0.440	<0.030	<0.300	<0.010	2.061	0.035	59
Freshwater	Waterton	0.013	1.687	1.301	<0.030	<0.300	<0.010	6.082	0.572	356
Invert	Rocky Mtn.	2.066	0.547	0.072	0.219	<0.300	0.061	2.070	0.128	8
Invert	G. Prairie	2.967	0.354	0.451	0.071	<0.300	0.028	1.990	0.249	11
KCl	Cold Lake	0.376	0.029	1.283	<0.030	<0.030	<0.001	5.353	0.009	40
KCl	Waterton	0.049	0.606	0.662	0.229	<0.300	<0.010	4.779	<0.030	50
NaCl	Cold Lake	0.259	<0.100	0.123	<0.030	<0.300	<0.010	5.375	<0.030	261
NaCl	Slave Lake	0.239	0.665	0.083	<0.030	<0.300	<0.010	2.110	0.125	78
Washed Inv.	G. Prairie	0.101	<0.100	0.077	<0.030	<0.300	<0.010	2.570	<0.030	2
Water-N.A.	Rocky Mtn.	0.049	0.108	0.059	<0.030	<0.300	<0.010	11.355	<0.030	4
Soil (DAP)	Cold Lake	0.098	0.845	<0.050	<0.030	<0.300	<0.010	27.664	<0.030	1
Soil	Cold Lake	0.099	0.545	<0.050	0.018	<0.300	<0.010	21.280	0.062	1
Soil	Slave Lake	0.228	0.705	<0.050	<0.030	<0.300	<0.010	16.400	0.067	1
Soil	G. Prairie	0.158	0.941	<0.050	<0.030	<0.300	<0.010	17.800	0.060	1
Soil	Rocky Mtn.	0.136	0.474	<0.050	<0.030	<0.300	<0.010	17.304	<0.030	0
Soil	Waterton	0.056	0.849	<0.050	<0.030	<0.300	<0.010	5.806	<0.030	0

DTPA extract data for the drilling waste and soil materials used in the pot experiments.

Waste	Location	Fe	Cd	Cu	Pb	Zn	Mn	Ca	Mg	Na	K	B	P	Mo
		(ug/g)												
DAP	Cold Lake	17.5	<0.25	7.25	27.75	39.50	10.00	292.3	40.0	1033.00	1294.0	1.75	36.00	0.50
Freshwater	Cold Lake	260.0	0.20	10.60	18.70	25.00	20.50	100.0	159.0	1730.00	247.0	3.60	4.80	1.70
Freshwater1	G. Prairie	217.1	0.11	5.99	15.80	14.02	11.98	293.8	87.8	4947.75	258.6	0.60	9.75	<0.25
Freshwater	Rocky Mtn.	82.0	<0.25	5.00	8.75	15.75	6.00	311.0	90.0	1540.50	204.0	<0.25	5.25	<0.25
Freshwater	Waterton	207.0	<0.25	10.75	31.50	36.50	17.25	212.3	48.5	238.00	826.5	0.50	3.50	2.75
Invert	Rocky Mtn.	37.8	<0.25	1.25	2.25	22.00	1.50	357.3	89.0	1393.00	375.3	0.50	1.25	<0.25
Invert	G. Prairie	91.5	<0.25	2.55	3.74	9.90	2.27	303.4	51.8	2512.50	588.3	1.24	0.82	<0.25
KCl	Cold Lake	220.0	0.20	8.20	10.90	57.00	15.60	149.0	94.0	2375.00	7830.0	2.30	2.50	1.20
KCl	Waterton	110.0	<0.25	5.75	38.00	151.25	9.00	183.5	149.0	6563.00	27799.0	0.75	2.25	0.50
NaCl	Cold Lake	171.0	<0.25	6.20	12.10	22.00	12.70	92.0	315.0	18250.00	89.0	1.90	5.40	<0.25
NaCl	Slave Lake	284.2	0.12	12.98	11.45	14.36	37.95	167.6	1021.5	11637.29	185.9	8.70	3.59	<0.25
Washed Inv.	G. Prairie	116.9	<0.25	3.33	5.84	11.62	2.83	266.3	33.0	135.47	263.7	0.80	0.72	<0.25
Water-N.A.	Rocky Mtn.	94.5	<0.25	3.00	5.00	39.25	2.75	311.0	101.5	340.50	160.3	0.75	1.00	<0.25
Soil (DAP)	Cold Lake	134.5	<0.25	0.50	0.25	0.75	1.75	443.5	190.3	5.25	115.5	<0.25	13.25	<0.25
Soil	Cold Lake	60.0	<0.25	0.60	0.50	0.40	2.40	405.0	170.0	26.20	80.5	<0.25	6.30	<0.25
Soil	Slave Lake	196.3	0.09	0.72	1.25	3.99	19.08	378.5	74.5	10.66	130.8	<0.25	14.13	<0.25
Soil	G. Prairie	257.5	0.16	1.71	1.52	2.75	28.45	363.5	136.4	13.06	215.7	<0.25	12.13	<0.25
Soil	Rocky Mtn.	207.0	<0.25	1.00	1.25	1.75	13.25	292.3	84.0	9.50	115.0	<0.25	8.75	<0.25
Soil	Waterton	264.5	<0.25	1.63	1.75	3.38	7.75	325.4	137.1	28.00	205.3	<0.25	8.88	<0.25

Concluded. DTPA extract data for the drilling waste and soil materials used in the pot experiments.

Waste	Location	Ni	Se
		— (ug/g)	–
DAP	Cold Lake	1.00	<0.75
Freshwater	Cold Lake	1.90	1.00
Freshwater1	G. Prairie	1.84	1.51
Freshwater	Rocky Mtn.	1.50	<0.75
Freshwater	Waterton	1.25	3.00
Invert	Rocky Mtn.	0.25	<0.75
Invert	G. Prairie	1.45	<0.75
KCl	Cold Lake	2.20	<0.75
KCl	Waterton	1.25	1.00
NaCl	Cold Lake	0.80	<0.75
NaCl	Slave Lake	2.92	3.10
Washed Inv.	G. Prairie	1.38	<0.75
Water–N.A.	Rocky Mtn.	0.75	<0.75
Soil (DAP)	Cold Lake	0.25	<0.75
Soil	Cold Lake	0.20	<0.75
Soil	Slave Lake	0.42	0.92
Soil	G. Prairie	1.49	1.01
Soil	Rocky Mtn.	0.50	<0.75
Soil	Waterton	1.50	<0.75

Total elemental analysis data of the drilling waste and soil materials used in the pot experiments.

Waste	Location	Mn	Na	K	Ca	Mg	Cu	Zn	P	Mo	Al	Fe	Ti	V	Cr
									(ug/g)						
DAP	Cold Lake	200	4914	7984	12319	6885	21.19	118.5	1145	<21.4	1914	15053	1079.4	48.8	44.4
Freshwater	Cold Lake	186	5410	7550	26880	4700	39.20	47.4	338	29.2	26320	12130	1190.0	66.0	47.8
Freshwater1	G. Prairie	366	7141	15138	7282	1729	38.71	134.5	961	25.9	48005	37318	3977.3	146.5	141.8
Freshwater	Rocky Mtn.	441	5611	15483	5214	3428	38.03	158.1	1117	27.7	48460	34248	3016.5	116.5	95.6
Freshwater	Waterton	403	15382	14154	5560	2139	42.12	212.5	425	26.1	54736	31696	98.5	98.5	300.4
Invert	Rocky Mtn.	223	5192	18368	4403	3806	35.94	257.8	752	34.6	52693	35842	3091.8	181.5	98.8
Invert	G. Prairie	218	4898	17160	8255	3836	25.36	132.8	741	<21.4	51908	31458	3599.1	176.5	96.5
KCl	Cold Lake	372	10950	33620	40560	9190	32.20	209.0	729	36.8	57640	25320	3115.0	131.0	136.5
KCl	Waterton	310	10712	39922	2823	3080	66.98	539.4	330	<21.4	13656	19958	1728.5	61.8	93.2
NaCl	Cold Lake	260	41820	11810	70200	14880	16.20	77.0	401	<21.4	37760	15600	1930.0	50.5	62.5
NaCl	Slave Lake	491	15615	11780	18343	7181	56.61	77.4	472	<21.4	7761	29220	2012.1	68.2	284.3
Water-N.A.	Rocky Mtn.	320	1027	12674	9303	21276	19.51	147.9	276	<21.4	2200	11522	1303.7	45.1	40.6
Soil (DAP)	Cold Lake	433	9406	19381	5204	1897	6.83	41.5	561	33.1	42249	17499	2558.7	46.0	49.1
Soil	Cold Lake	282	7840	12450	5460	2840	4.90	23.2	286	<21.4	33420	12280	1640.0	32.2	35.2
Soil	Slave Lake	315	5867	11756	3150	1467	10.16	36.0	440	<21.4	34655	17721	2898.4	61.0	81.6
Soil	G. Prairie	669	6121	14080	3211	1915	18.40	66.6	707	<21.4	48795	24488	3148.4	104.6	78.6
Soil	Rocky Mtn.	520	8963	11649	755	1395	38.57	130.9	917	<21.4	65372	46334	4202.6	136.1	75.9
Soil	Waterton	648	5849	15740	5635	2625	19.69	78.2	661	<21.4	48516	23299	2679.0	85.0	57.4

Concluded. Total elemental analysis data of the drilling waste and soil materials used in the pot experiments.

Waste	Location	Ba	Ni	Sr	Li	Zr
				(ug/g)		
DAP	Cold Lake	37.27	30.6	55.1	20.7	<7.90
Freshwater	Cold Lake	431.00	35.2	111.0	60.5	106.5
Freshwater1	G. Prairie	422.10	41.8	126.8	49.4	127.8
Freshwater	Rocky Mtn.	362.60	51.9	116.8	45.1	83.1
Freshwater	Waterton	259.55	37.7	168.9	32.6	100.9
Invert	Rocky Mtn.	414.20	46.8	127.0	63.6	69.8
Invert	G. Prairie	620.32	41.6	160.5	62.7	91.2
KCl	Cold Lake	749.00	37.6	240.0	91.0	133.5
KCl	Waterton	650.77	28.9	246.4	62.7	69.0
NaCl	Cold Lake	430.00	18.2	192.5	59.5	98.5
NaCl	Slave Lake	292.08	30.7	158.6	52.1	75.5
Water-N.A.	Rocky Mtn.	8.70	27.4	41.7	33.0	<7.90
Soil (DAP)	Cold Lake	477.75	23.0	130.0	26.3	126.5
Soil	Cold Lake	461.00	20.6	117.5	16.7	116.0
Soil	Slave Lake	230.37	18.5	80.0	25.5	118.8
Soil	G. Prairie	292.75	29.0	84.2	40.4	105.7
Soil	Rocky Mtn.	538.81	34.1	63.4	39.6	85.4
Soil	Waterton	616.37	30.9	101.5	33.6	94.6

Reclamation Research Reports

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. $10.00**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. $10.00**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. $10.00**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their uninoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition.**
Hardy BBT Limited. 436 pp. $10.00

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that preceeds each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

58. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw.**
188 pp. $10.00

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

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